The Diminishing Signaling Value of Patents between Early Rounds of Venture Capital Financing

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1. Introduction

Patents reflect improvements in innovation and can contribute to the performance of firms and their market value (Bloom and Van Reenen, 2002; Griliches, 1981; Hall, 2004; Hall et al., 2005). The linkage between patents and firm performance has been attributed largely to monopolistic market rights and future technology options, protection from competitors, and improvements in the negotiating position of patent holders with partners, investors and remaining stakeholders (Blind et al., 2006; Gans et al., 2002; Giuri et al., 2007; Harabi, 1995; Helmers and Rogers, 2011; Levitas and Chi, 2010; Silverman and Baum, 2002; Teece, 2000).[1]

A relatively less studied linkage between patents and firm growth is the value of patents as signals and situations where external investors, such as venture capital firms (VCFs), are attracted to firms with patents. Indeed, there are good theoretical reasons to expect such relationship (Graham et al., 2009; Heeley et al., 2007; Long, 2002). For instance, in knowledge intensive industries, the value of emerging firms that seek external finance can be difficult to assess because such firms often lack a track record and they are confronted with technical, scientific and regulatory challenges that are either unknown *ex ante* or difficult to manage *ex post* (Harhoff, 2011). Ownership of patents, however, can signal the potential of a firm to external investors through possible future developments with commercial value (Hagedoorn et al., 2000; Heeley et al., 2007). Further, because patents confer monopolistic market rights, which can then lead to sustainable competitive advantage, investors may place a market value on these rights, and consequently invest in the firm that possesses them.

To corroborate such theoretical expectations a handful of empirical studies has documented that patents attract prominent VCFs, prompt VCFs to invest faster and generally

[1] On a macro level, patents have been associated with increasing national economic growth and the development and diffusion of knowledge (Blind and Jungmittag, 2008; Shapiro and Hassett, 2005).

increase the amounts invested in firms that own them (Audretsch et al., 2012; Baum and Silverman, 2004; Cao and Hsu, 2011; Conti et al., 2013; Engel and Keilbach, 2007; Häussler et al., 2009; Hsu and Ziedonis, 2013; Mann and Sager, 2007). [2] In this literature, only few studies tease out the signaling function of patents from the economic function (Cao and Hsu, 2011; Hsu and Ziedonis, 2013). Further, in this body of work the effect of patents on venture capital attraction has mostly been studied as a snap shot in time by focusing, for instance, on the amount of venture capital raised by a target firm over a certain period. As a result, what is largely unknown is whether the signaling value of patents in attracting VCFs diminishes over time as investors and target firms become more acquainted with each other. This question is the point of departure for the present study which contributes to a scant literature that deals with the dynamics of patent signals.[3]

To form our theoretical expectations we reflect upon the main arguments regarding the relationship between patents and venture capital attraction. These arguments focus, in large part, on the reduction of information asymmetries between VCFs and target firms. But, if such asymmetries lessen as VCFs and target firms become more familiar with each other over time, then the value of patents as a signal should also decrease. To study this proposition we leverage the tendency of VCFs to invest in target firms through sequential rounds of financing. Through such rounds, VCFs provide funds to a particular firm after it has met certain milestones that relate, mainly, to technical progress (Gompers, 1995). This sequential structure of VC investments allows us to detect patterns that would otherwise not be apparent. More specifically, each additional round of financing can reduce the information asymmetries between VCFs and the target firm because VCFs gather new information about the firm through monitoring, management and other forms of hands-on involvement with the firms they invest in (Gompers, 1995; Ruhnka and Young, 1987; Wang and Zhou, 2004). Accordingly, the effect of

[2] There is also evidence linking patents to successful Initial Public Offerings (e.g. Cockburn and MacGarvie, 2009; Heeley et al., 2007).
[3] The present study is also informative for the stream of literature investigating whether venture capital promotes or follows innovation (Hirukawa and Ueda, 2011; Ueda and Hirukawa, 2008).

patents on attracting venture capital via a signaling process should diminish through sequential rounds of financing.

To test our theoretical expectations we employ a rich dataset that measures patent activity (granted patents and number of patent applications) from firm birth to the first round of financing and then again from the first round of financing to the second round for more than 580 U.S.-based dedicated biotechnology firms (DBFs) that received funds from VCFs from 2001 to 2011. We focus our attention on the first two rounds of financing because in these rounds information asymmetries between investors and target firms are expected to be more pronounced. Therefore, by concentrating on these rounds we can detect the impact of information asymmetries on the effectiveness of patent activity as a signal. We focus on biotechnology because it is a knowledge intensive industry in which information asymmetries between investors and firms are expected to be significant. Hence, patents as signals could be relevant in this industry (Higgins et al., 2011; Janney and Folta, 2003). Furthermore, patents are popular among biotechnology firms (Fligstein, 1996) and existing evidence suggests that compared to other high technology industries, investors weight patents more heavily in biotechnology when they make investments decisions (Sichelman and Graham, 2010) perhaps because of the strong link between innovation and patents in that industry (Arundel and Kabla, 1998). Biotechnology is also an industry that receives large amounts of (staged) venture capital investments reflecting the risky nature of the industry as well as the potential for high returns (Baum and Silverman, 2004; Gompers and Lerner, 2001). Together, these industry characteristics suggest that if patent activity serves as a signal for investors whose value diminishes over time, evidence of such dynamics should be apparent across biotechnology firms.

For our empirical analysis, we construct models that associate patent activity before and after a round of financing with the amount invested to each firm and we control for regional and VCF-specific characteristics that could influence the level of investment. To separate the function of patents as a signal from their economic value potential, both of which can attract investors and capital, we account for the differential (economic) quality of patents. We also

control for the firm growth stage funds are directed to as well as for the reputation of the investors, both of which can influence the amount of capital invested in a firm. To isolate the strength of patents as a signal from other signals firms can employ we include relevant control variables, such as the presence of distinguished scientists on the board of directors.

Our interest in the value of patents as signaling mechanism for capital investments in small firms and specifically on whether such value diminishes over time is motivated by more than academic curiosity. Answers to these questions have important policy implications. The number of patents and patent applications have increased substantially over the years (Kim and Marschke, 2004; Kortum and Lerner, 1999) and so have the costs associated with processing patents. Such issues have prompted questions about the effectiveness of the current patent system and especially with regard to the degree that it puts smaller firms in a disadvantage and thus potentially hinders innovation (Bessen and Meurer, 2008; Jaffe and Lerner, 2004). Assessing whether patents increase private sector investments in small firms and whether such increase is affected by the familiarity between VCFs and target firms, needs to be taken into account when policy makers and other stakeholders consider the effectiveness of the current patent system.

We proceed with the rest of the paper as follows: In section 2 we review the literature on the functions of VCFs and how patents can act as signals and form our hypotheses. In sections 3 and 4 we present our methodology and data. In section 5 we present our results and we conclude in section 6.

2. How patents can act as signals to investors

In their most common form of arrangement, venture capital firms pool capital from institutional investors such as pension funds and university endowments. VCFs, in turn, use these capital pools to make investments and tie their compensation to the returns of those investments. Because the VCFs manage a rather small share of the funds maintained by institutional investors, the risk exposure of each institutional investor is relatively limited. Accordingly,

VCFs can afford to invest in risky ventures that have the potential to yield returns above 25 percent per year so that they maximize their compensation as well as the compensation of the institutional investors (Zider, 1998).

A popular investment target for VCFs is young firms in high technology areas such as biotechnology. These firms offer investors a potential for high returns (Carpenter and Petersen, 2002) but also high risk as they grapple with highly complex scientific problems associated long research cycles and challenging legal environments (DiMasi and Grabowski, 2007; Häussler and Zademach, 2007). Because of such conditions and because of their young age, firms in such sectors may find it difficult to generate current cash flows or establish a record of future cash flows. Accordingly, even when firms in such sectors fully understand their potential, they might still find it difficult to convey it to VCFs. This creates a mismatch in the information possessed by firms and that possessed by VCFs. As a result, the relationship between VCFs and target firms before an investment takes place is commonly prone to information asymmetries (Cumming, 2005; Sahlman, 1990).

To overcome such information asymmetries, firms seeking capital often use signals that partly substitute for the lack of an established record and can portray their potential (Busenitz et al., 2005; Certo et al., 2001; Podolny, 1993, 2010; Zhang and Wiersema, 2009). In fact, whenever information asymmetries are present, VCFs tend to rely on signals of this sort before they make investment decisions (Amit et al., 1990; Higgins and Gulati, 2006) because separating, *a priori* , high-quality start-ups from firms with less potential can be difficult (Davila et al., 2003). Along these lines, a number of studies demonstrate that, in general, signals can reduce information asymmetries (e.g. Cohen and Dean, 2005; Gimmon and Levie, 2010; Higgins et al., 2011; Hsu, 2007; Janney and Folta, 2003; Mishra et al., 1998).

The next relevant question then is whether patents can effectively act as such a signal. Strong signals are observable and costly to imitate (Cohen and Dean, 2005; Spence, 1973). Additionally, signals which are governed by strong institutions and hence conform to certain institutional standards tend to increase in value (Janney and Folta, 2003). This holds largely because conformity reduces variation across signals and can thus limit the impact that the

subjectivity of the receiver can have on the valuation of the signal (Fischer and Reuber, 2007; Perkins and Hendry, 2005). Patents would therefore appear to meet the requirements for a valuable signal because they are easily observable, costly to acquire (Graham et al., 2009) and are governed strictly. For firms in knowledge intensive industries where information asymmetries are typically strong (Chaddad and Reuer, 2009), patents may have increased value for investment decisions (Sichelman and Graham, 2010) because they relate to invention and innovation which in turn can lead to commercial gains (Acs et al., 2002; Arundel and Kabla, 1998; Griliches, 1998).

Empirical evidence on whether patents actually serve a signaling function that augments the accumulation of capital for a given firm is scarce as it amounts, as far as we are aware, to two contributions.[4] The first study is by Cao and Hsu (2011) who find that startups with patents were more likely to issue an IPO; the authors demonstrate the signaling function of patents by empirically controlling for a number of remaining factors that can lead to the issuance of an IPO (e.g. growth options of a given firm and technological uncertainty). Nevertheless, Cao and Hsu (2011) focus on the impact of patents on the occurrence of an IPO without investigating the impact of patents on intermediary financial milestones a company needs to go through before it issues an IPO. Accordingly, whether patents had a stronger effect in the early financial performance of the firm when compared to the later financial performance as measured by the IPO was not part of the analysis. The second relevant study we identified, by Hsu and Ziedonis (2013) is the most informative with respect to the potential dynamics in the signaling contribution of patents. In their analysis of firm valuations, the authors find that patents are more effective in attracting prominent investors and boosting firm valuations during early

[4]The scarcity of research can largely be credited to the inherent difficulties of attributing positive associations of patent activity measures and capital investments solely to signaling. In particular, while some studies report that larger patent portfolios associate with enhanced performance metrics such as the issuance of an IPO and the growth of external financing for a given firm whether such relationships emanate from the signaling value of patents or from the economic value of patents is not entirely clear (Audretsch et al., 2012; Baum and Silverman, 2004; Conti et al., 2013; Engel and Keilbach, 2007; Mann and Sager, 2007). A quote from Conti et al. (2013) describes the issue with precision: ...we cannot empirically separate the signaling value of patents from their productive contribution..". Finally, note that while Häussler et al. (2009) provide evidence of patents serving as signals, they do not study the accumulation of funds and as such it is difficult to extrapolate their findings to our case.

investment rounds, which is a finding that supports the expectation that patents act as a signal whose value diminishes over time.[5]

In sum, the evidence on whether the signaling value of patents wanes once investors have a better insight into the value of the firms they injected capital is particularly thin. Hence, it is difficult to infer whether and how the value of patents as signal diminishes once the quality of the firm is assessed more closely by investors.

To answer this question we refer to the literature that examines how VCFs reduce information asymmetries once they have invested in a firm. The starting point of this literature is the basic insight that information asymmetries lead to agency problems (Fama, 1980; Jensen and Meckling, 1976). A major task of VCFs is therefore to reduce agency problems of this sort. A typical mechanism that VCFs use for this purpose is to provide funds in rounds of financing (Neher, 1999; Wang and Zhou, 2004). Under this mechanism, target firms receive funds of a particular round conditional on having received funds in a previous round (and have met certain milestones). Between rounds, VCFs become actively involved in the day-to-day operations of the target firm via consulting and monitoring (Gorman and Sahlman, 1989; Rosenstein et al., 1993). In doing so, VCFs follow the progress of the firms they invest in, evaluate their prospects and generally get more acquainted with their activities and potential. It follows that information asymmetries between VCFs and target firms should decrease under these conditions. In environments with reduced information asymmetries the value of signals tends to decrease (Gulati and Higgins, 2003; Higgins and Gulati, 2006). By extension, once a VCF is

[5] In particular, in their analysis of firm valuations, the authors include a dummy variable that takes the value of 1 if the valuation refers to the first or second round of investment and report a positive coefficient for the interaction term of this variable with the patent activity variable; implying thus that patent activity is more effective in boosting firm valuation for early investment rounds. Besides differences in sample size (370 versus 530 firms), period of analysis (1975 to 1999 versus 2001 to 2011), industry focus (semiconductor versus biotechnology) and different measures of patent activity (patent stocks versus applications and granted patents) a fundamental distinction of our work is that we are interested in the transition of the signal value of a patent after the first round of investment has been completed, where we expect information asymmetries between firms and VCFs to greatly diminish. Accordingly, we treat investments in round 1 and round 2 as separate and we do not aggregate them in a composite "early rounds" measure. As a result, we study the dynamics of the signaling value of patents between early rounds of financing while Hsu and Ziedonis (2013) focus on the dynamics between early and later stage financing.

familiar with the target firm, the effectiveness of patents as signals for attracting additional funds is therefore expected to be limited.

More specifically, it may be reasonable to expect that patents, through signaling effects, can augment the amounts of venture capital raised by firms in their first round of financing. Patents, however, should not be expected to have a significant signaling effect on the amount raised in the second round of financing because the, initially, hidden quality of the firm should now be more apparent to the VCF. Indeed, insofar patents are a quality signal, those acquired after the first round should not materially influence the amount of funds raised in the second round.[6] We expect this to hold because if the unobserved quality of the firm is, in large part, revealed to the VCF, the need for additional signals lessens.[7] Taken together, the foregoing discussion leads to the following hypotheses:

H1: Patent activity before the first round of financing acts as a signal that increases the amount of funds raised in the first round of financing

H2: Patent activity before the second round of financing does not act as a signal that increases the amount of funds raised in the second round of financing

To illustrate our theoretical expectations, Figure 1 presents the dynamic nature of the interaction between VCFs and target firms. This interaction underpins the diminishing signaling value of patent activity and forms the basis of our hypotheses.

-----Figure 1 about here ----

In the next section, we explain how we go about testing empirically our hypotheses.

[6] Note that if the quality of the firm changes after the first round, patents after the first round can again act as a quality signal primarily for new investors. For investors that participated in the first round we expect the day to day interactions with the firm to alleviate their need for additional signals. For our sample the large majority of firms received funds from the same sole investor and very few firms received funds from a different set of investors between rounds. As such, we expect our main hypotheses to hold for the vast majority of cases at hand.

[7] Following the same line of reasoning, if patents are valued by VCFs primarily for their implied discounted rents, patents after the first round should be expected to increase the amount of funds for the second round as well.

3. Methods and Procedures

To empirically test our hypotheses that the signaling value of patents will tend to decline as capital investment in small firms proceeds in sequential rounds, we need to associate the patent activity of a firm with the incremental amount of venture capital it attracts while information asymmetries between investors and the firm diminish over time. We operationalize patent activity with the number of granted patents a firm has received and the number of patent applications it has filled. To test whether the effectiveness of patent activity as a signal declines as a result of reduced information asymmetries we build two empirical models. In the first, the sum of venture capital funds raised by a given firm in the first round of financing when information asymmetries are expected to be stronger is regressed on patent activity. In the second model, the sum of venture capital funds raised by a given firm during the second round of financing at which time information asymmetries are expected to decline, is again regressed on patent activity measures. The dependent variable in each model is the natural log of the total amount of VC funding raised by a given biotechnology firm in round 1 (model 1) or round 2 (model 2). We present the right-hand side variables below.

We include patent activity as an explanatory variable in both models. We separate the number of granted patents from the number of submitted applications because their signaling values might differ in subtle but important ways (Gans et al., 2008; Popp et al., 2004). For instance, preparing a patent application is a lengthy and time consuming process which entails the presentation of complex technical issues in a structured format (Häussler et al., 2009). Further, during the correspondence of the applicant with the patent office, the applicant may be prompted to fine-tune the application, become familiar with more strands of relevant research and generally be exposed to situations that can mature the company and help it develop. In fact, mainly because of the harmonized strict requirements that a firm needs to comply with for all of its patent applications, it is conceivable that the patent acquisition process is subject to a learning curve. In turn, emerging firms that have applied for a number of patents may be

learning more by being more often involved in the patent acquisition process.[8] Accordingly, the number of patent applications may have a signaling value in that investors may view firms developing further rather than sitting idle.[9] In contrast, granted patents may signal that firms are well down the path of the learning curve. It is therefore of interest to test whether the pull on capital is sensitive to the different potential signaling value offered by granted patents and experience with patent applications. Indeed empirical evidence indicates that patent applications may have a stronger signaling effect than patents in attracting venture capital faster and at larger volume (Baum and Silverman, 2004; Häussler et al., 2009). For all these reasons, we consider these two forms of patent activity separately in our models.

For the first round of financing we measure the number of patents and patent applications from firm birth until the date of financing and expect positive signs for the corresponding coefficients. Such signs would indicate that patent activity acts as a signal and increases the level of venture capital funds invested in the focal firm (*PatentApp_1* and *PatentGrant_1*). For the second round of financing we maintain our measures of patent activity we use in the first specification and we also add two independent variables that measure the number of granted patents and patent applications filled from the date of the first round of investment until the date of the second round of investment (*PatentApp_2* and *PatentGrant_2*).[10] As discussed in section 2, *PatentApp_1* and *PatentGrant_1* are included in

[8] As noted, our expectation on the signaling value of applications emanate from a learning-by-doing process and a fine-tuning process. The measure of applications we use (number of applications submitted) is consistent with both processes. It captures the learning-by-doing effects because it measures the intensity a given firm applies for patents. It captures the fine-tuning process because a. the length of time it takes from an application to be granted at the USPTO is extensive (Mabey Jr, 2010), on average two and a half years for our sample patents, and b. between 85 to 90 percent of applications turn to patents at the USPTO (Quillen and Webster, 2001). As such, the more applications a firm submits the more exposed it becomes to fine-tuning procedures because chances are that before the applications become patents there is extensive communication between the firm and the patent authorities.

[9] While empirical evidence on the drivers of signaling value of the intensity a given firm submits patent applications is scarce, personal correspondence of the authors with Dutch and US-based VCFs attends to this argument. This correspondence also indicated that potential differences in the economic value between applications and granted patents (e.g. applications but not granted patents are open to revisions that could create uncertainty for competitors) does not typically weigh in heavily in investment decisions particularly for VCFs with expertise and experience to approximate beforehand the granted claims of a given application.

[10] As we illustrate in Appendix Figure 1, to avoid double-counting *PatentApp_1* measures only the number of applications that were not granted patent rights before the first round (for the round 1 regression) or between the first and the second round (for the round 2 regression); that is we exclude

the analysis of the second round in order to test whether patent activity indeed serves a signaling function; if it conveys a quality signal, then *PatentApp_1* and *PatentGrant_1* should have explanatory power for the funds raised in the first round of financing but not for the second. Along the same lines, under the premise that patent activity serves a signaling function, *PatentApp_2* and *PatentGrant_2* should not augment the amount of funds raised in round 2. If other potential advantages conferred by patents, such as discounted rents, are the prime reasons for the attraction of VCFs to patents, then *PatentApp_2* and *PatentGrant_2* should have significant explanatory power in the amount of funds raised in round 2. Therefore, in line with our hypotheses, we expect the patent activity before the second round of investment to have a diminished influence on the level of venture capital funds received by the focal firm in the second round.

In order to most effectively evaluate whether patents act as a signal that can attract venture capital funds, we need to account for the differential economic value of patents as VCFs will tend to invest in firms with the highest quality of intellectual property and greater future value. That is, we need to tease out the (economic) value of the patent itself from its signaling value. To do so, we follow previous literature (Gambardella et al., 2008; Harhoff et al., 2003; Häussler et al., 2009; Trajtenberg, 1990) and we approximate patent economic value with a variable that measures the average number of times a patent has been cited by other patents (i.e. forward citations) (*PatentCiteYear_1*) [11]. Higher citation levels imply superior scientific

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applications whose grant we include in the *PatentGrant_1* and *PatentGrant_2* variable. As a consequence, the *PatentApp_1* variable for a given firm can be different across regressions: if an application was applied for before round 1 and it was granted between round 1 and round 2, it is included in the *PatentApp_1* variable in the round 1 regression but not in the *PatentApp_1* variable in the round 2 regression. Overall, the scheme we employ to construct our patent activity variables could materially truncate the *PatentApp_1* variable insofar as a. the elapsed time between the founding of the firm and the receipt of first round funds was extended or b. the elapsed time between financing rounds was extended. But, as we show in Tables 1a and 1b and explain in footnote 25: a. on average, our sample firms received their first round of financing almost 30 months (2.54 years) after their birth and b. the average elapsed time between rounds in our sample is 13 months. Both of those figures are below (or closely approaching) the average 30 months that elapsed between the application and the grant date at the USPTO for the patents in our sample. It follows that from either source of potential truncation, the truncation is minimal. To illustrate, only 17 applications whose patent pendency time was below 13 months were omitted from *PatentApp_1* because they were included in *PatentGrant_2*. Including these applications in the analysis yields qualitatively similar results.

[11] Our choice to use forward citations as a proxy for patent economic value is based on strong empirical evidence. For instance, recent results suggest that forward citations are reliable predictors of the auction

significance or applicability and are taken to indicate higher quality patents. Indeed, Fischer and Leidinger (2013) and Sneed and Johnson (2009) when they correlate the auction price of patents --- a direct measure of patent economic value --- with the number of forward citations reveal that forward citations are closely associated with the economic value of patents. In the specification of the second round, besides *PatentCiteYear_1* we also include a similar variable that measures the forward citations of patents granted from the date of the first round until the date of the second round (*PatentCiteYear_2*). [12] We expect patents of higher economic value to attract greater amounts of funds in both investment rounds.

The patent activity of a focal firm before the first round of financing is by definition unaffected by the involvement of VCFs in the firm. But, the patent activity before the second round of investment can be influenced by managerial advice under the consulting role that VCFs assume once they invest in a firm. That is, if patent activity after the first round is influenced by the involvement of VCFs in the firm, the empirical model of round 2 could suffer from specification bias. To account for it, in the specification of the second round we include in the lagged dependent variable in level form (i.e. the dependent variable in the first specification, in level form, which is the total amount invested in the first round of investment –

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price of patents (Fischer and Leidinger (2013); Sneed and Johnson (2009)). Because in patent auctions the bidders buy only the patent and not the seller firm (or any other type of institutions that holds the patents) this setting is as close as one can get to reliably approximate the economic value of patents. Nevertheless, the small number of studies that have provided these estimates may cast some doubt about their generalizability. Towards this end, an important observation is that the patent value estimates from Fischer and Leidinger (2013) and Sneed and Johnson (2009) are well within the range of patent value estimates reported previously from studies that do not use patent auction data (e.g. Trajtenberg (1990)) and as such they may be measuring both the economic and the signaling value of a given patent. The observation that the patent value estimates from the auction and the non-auction studies are within range is important because a. it implies that even in the non-auction settings what is captured is, for the most part, economic patent value and b. given that forward citations explain a significant part of the patent value derived by non-auction settings (Trajtenberg (1990)), it significantly extends the empirical evidence demonstrating that forward citations capture economic patent value. Finally, in alternative approaches to estimate the economic value of a given patent (i.e. by asking investors the price they would sell their patent had they known its value *a priori*) the evidence, again, shows that forward citations are the most reliable proxy (Gambardella et al., 2008). Importantly, as robustness check in section 5.2 we present models in which we employ different measures of patent economic value (patent family size) and reach similar conclusions to our baseline models.

[12] Note that the number of forward citations is not a measure that is fully observable by the VCFs when they invest in the firm because VCFs are able to observe only the citations that have been received by the time they invest. Further, more recent patents tend to receive fewer citations compared to older patents mainly due to the effective time a patent may need until it becomes visible. To account for this observation we divide the average number of forward citations for the patents of a given firm by the age of the patent measured in years (citations are measured up to early summer of 2012). Then, we average out the average number of forward citations per firm patent.

VCF_Investment_1) (Baum and Silverman, 2004; Jacobson, 1990).[13] Given that conditional on the receipt of funds, the amount per round generally increases with more advanced rounds (Gompers, 1995), we expect a positive sign for this variable.

In return for their investment, VCFs become part owners of the target firm. The size of the amount they invest in order to become part owners depends heavily on two factors: i) the valuation of the firm *ex ante* and ii) the percentage of equity they receive. It follows that we need to account for both of those factors but finding direct measures for such factors is empirically challenging. As such, we use two indicators that can approximate the conceptual variables. Specifically, for both rounds we construct round-specific variables that assume increasing values for investments directed towards later stages of firm growth (*GrowthStage_1* and *GrowthStage_2*).[14] Generally, the valuation of firms, *ex ante*, increases with the stage of firm growth (Cumming and Dai, 2011) and in this respect these indicators should approximate firm valuation. Importantly, early and later stage investments by VCFs are also typically associated with different equity shares (Beaton, 2010; Kaplan and Strömberg, 2003). As such, the *GrowthStage* indicators should be correlated with the amount of equity secured by VCFs. Given the increased valuation that accompanies firms at later stages of firm growth, we expect a positive sign for the variable at hand. We also construct another indicator to approximate the fraction of equity VCFs receive in exchange for their investments which is based on the finding that VCFs with stronger reputation typically receive larger equity than investors with weaker reputation for the similar investment (Hsu, 2004). As such, we include in both specifications a

[13] Lagged dependent variables are generally more meaningful in panel data structures. While lagged dependent variables in cross sectional data, like in our application, are less regular, they have been used previously (see Hochberg et al., 2007 for an example). Nevertheless, in order to test for the empirical relevance of the lagged dependent variable included in our models, in unreported models the estimates from specifications that do not include the lagged variable are largely in line with the main results presented in Table 3 and imply that the inclusion of the lagged dependent variable does not greatly influence our empirical estimates.

[14] Venture capital investments are directed towards different phases of firm growth, with each phase associated with different degrees of risk exposure and potential returns to the investor (Flynn and Forman, 2001). Seed stage funds are typically small amounts directed primarily towards proving a concept. Early stage funds are directed mainly towards product development. Funds directed towards the expansion stage are used, in large part, to boost market entry or strengthen R&D (Jeng and Wells, 2000). There are also funds directed towards later stage financing, such as buy-outs or acquisitions.

variable that reflects the Lee et al. (2011) reputation score of the highest ranked funding VCF of the first round of financing (*VCFreputation_1*).[15]

To account for additional signals used by emerging firms that tend to leverage the reputation and previous business history of the team around the firm (Arvanitis and Stucki, 2012; Audretsch and Stephan, 1996; Bonardo et al., 2011; Certo, 2003; Elitzur and Gavious, 2003; Gompers et al., 2010; Lee, 2001; Shane, 2000) in both specifications we include a variable that takes the value of 1 if one of the founders of the focal firm is a preeminent member of the academic community[16] and/or has started a firm previously (*FounderSignal*). Along the same lines, once the venture capital investment has been made, the reputation of the investors can also act as a signal since successful investors are presumed to possess skills that allow them to effectively identify firms with economic potential (Casamatta and Haritchabalet, 2007; Sorenson and Stuart, 2001). By extension, we expect the abovementioned variable *VCFreputation_1* in the specification of the second round to also capture effects of this kind. In line with the discussion in section 2, we expect *FounderSignal* to influence the total amount invested in the first round of financing and this effect to die off for the second round. For *VCFreputation*_1 we expect it to be positively related with the total venture capital amount raised in the second round of financing.

In addition to the signaling effect that funding VCFs can have, their availability of funds can also influence the growth of venture capital funds invested in a given firm. Because such availability is often largely determined by the number of investors that spread the risks of their investments (i.e. by the syndication size) (Lockett and Wright, 2001) as well as by the capital available to the investors (Gupta and Sapienza, 1992; Tian, 2011) we include two variables that measure the number of investors per round as well as their average size in both specifications and expect positive signs for both coefficients (*SyndicateInvestors1,*

[15] As we explain in section 4, in our dataset the investors of round 1 and round 2 are largely the same. As a result, to avoid double-counting, in the specification of the second round we include only the reputation score of the round 1 investors and not the round 2 investors. Nevertheless, even when the reputation of the round 2 investors is included in the analysis, the results remain nearly identical to the baseline estimates.

[16] We code an academic founder as eminent if she holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or has won a Nobel Prize.

SyndicateInvestors2, *SyndicateSize1*, *SyndicateSize2*). Since in syndicates of VCFs the most proximate VCF is usually the most heavily involved in the day-to-day operation of the target firm (Ferrary, 2010), the last variable we include in the empirical models that relates to the funding VCFs is the distance between the most proximate funding VCF and the target firm (*DistanceClosestVCF*). Spatial proximity between target firms and investors typically eases the monitoring functions of VCFs (Sorenson and Stuart, 2001; Zook, 2005) and can lead to higher investments (Tian, 2011). We therefore expect a negative sign for the coefficient of this variable.

Because agglomeration externalities (e.g. knowledge spillovers and network effects) from different types of organizations often positively influence the performance of high technology firms (Coenen et al., 2004; Döring and Schnellenbach, 2006; Gittelman, 2007; Kolympiris and Kalaitzandonakes, 2013a, b; Kolympiris et al., 2011) we include in both specifications variables that account for such potential influences. The first variable measures the number of universities that perform biotechnology related research and are located in the same MSA as the focal firm (*UniversitiesInMSA*) and we expect a positive sign (Abel and Deitz, 2012; Anselin et al., 2000; Varga, 2000). As well, we account for potential proximity effects from the presence of VCFs and over-performing DBFs in the vicinity (Beaudry and Breschi, 2003; Gompers, 1995; Shane and Cable, 2002). Following Kolympiris et al. (2011) for each round of financing we construct corresponding variables that measure the density of VCFs and the number of patents granted to biotechnology firms before the focal financing round in 0 to 10 and 10 to 20 miles from the origin firm respectively (*VCFarea_0010_1*, *VCFarea_1020_1*, *VCFarea_0010_2*, *VCFarea_1020_2*, *PATENTarea_0010_1*, *PATENTarea_1020_1*, *PATENTarea_0010_2*, *PATENTarea_1020_2*) . We expect positive signs for the corresponding coefficients.

We also measure the age of the focal firm at the round of financing (*Age1*, *Age2*). We do not form strong priors with regard to the direction the age of firms can move the amount of funds received because VCFs may evaluate positively older firms due to higher experience and survival but they may also view negatively older firms that have not received previous

financing. To incorporate in the analysis year-to-year variations such as "hot IPO market" periods (Lowry and Schwert, 2002)[17] that can encourage or discourage venture capital investments at an aggregate level we include in our empirical models a set of year dummies that match with the year in which the investment took place.

With respect to estimation techniques, we employ White's standard errors because the heteroskedasticity tests we conduct (seen in Tables 2 and 3) show evidence of heteroskedasticity. We also test for the possibility that some of the errors in our models might be correlated. This may hold largely because there are often regional factors that are difficult to observe and which can affect the performance of all firms in a region or the capital investments they attract. For instance, such factors may include state subsidies and technical assistance for the development and financing of high technology firms and other such activities.[18] Factors of this sort can therefore cause DBFs of a given state to overperform or underperform jointly. If such influences do exist, the assumption of independence across observations for firms in the same state may be violated (Nichols and Schaffer, 2007; Stimson, 1985). To address this possibility we estimate both specifications with standard errors of firms in the same state modeled as correlated (i.e. clustered at the state level).

[17] On top of the variables described in this section, we further tested the influence of a number of moderation and interaction terms (e.g. the influence of the founder signal on the impact of the firm growth stage variables as a means to control for possible cofounding effects on the valuation of firms by VCFs). These variables did not improve significantly the statistical fit of the empirical models and they were generally not statistically strong. As such, we omit them from the analysis. However, we maintain in the analysis one of the interaction terms we tested for; the interaction between *PatentGrant_1* and *UniversitiesInMSA* in large part because we consider it particularly relevant from a theoretical perspective in that it tests whether the knowledge generation of nearby universities influences the impact of the signaling value of patents.

[18] Additional factors may refer to attitudes towards risky investments or the efficacy of consulting organizations (e.g. the Larta Institute or Foresight S&T) that can assist firms in improving their performance. Such features can expand beyond the geographic boundaries of 10 or 20 miles, which is the geographic boundary for the variables we employ to describe the regional environment. Largely because of the qualitative nature of those features, representing them through associated variables is a task with mounting difficulties and as such we opt for clustering the standard errors at the state level to control for their potential effects. The analysis with the clustered standard errors is conducted by estimates produced with generalized estimating equations which is a method of calculating the standard errors by first estimating the variability within the defined cluster (in our application the state) and then sums across all clusters (Zorn, 2006).

4. Data sources and presentation

To perform our empirical analyses, we began by measuring all venture capital investments toward dedicated biotechnology firms (DBFs) from 2001 up to 2011 using Thomson Reuter's SDC Platinum Database (SDC).[19] We also sourced from SDC the address and founding date of each DBF, the amount invested per round, the firm growth stage each investment was directed to, the date of financing round, the investors per round as well as their address and previous investments. We used this information to construct our dependent variables (*USD_R1* and *USD_R2*) and *Age1, Age2, SyndicateInvestors1, SyndicateInvestors2, SyndicateSize1, SyndicateSize2, DistanceClosestVCF, VCFarea_0010_1, VCFarea_1020_1, VCFarea_0010_2, VCFarea_1020_2, GrowthStage_1, GrowthStage_2*. For *DistanceClosestVCF, VCFarea_0010_1, VCFarea_1020_1, VCFarea_0010_2, VCFarea_1020_2* we needed to calculate the distance between the target firm and investors and the density of VCFs in a region.[20] To do so, we converted the addresses of target firms and VCFs to coordinates at http://batchgeo.com. Subsequently, we plugged these coordinates in the distance formula[21] we employ and constructed the corresponding variables.

For our variables *PatentApp_1, PatentGrant_1, PatentApp_2, PatentGrant_2* we used Google Patents ® which indexes granted patents and patent applications from the United States Patent and Trademark Office (USPTO).[22] We searched for every granted patent and patent

[19] We focus on this time period because for this period the number of patents and patent applications are available from the United States Patent and Trademark Office (USPTO). Before November 29, 2000 there was no formal obligation for the publication of patent applications from the USPTO. To test the sensitiveness of our empirical estimates to having only observations after 2001 in section 5.2 we present models that include venture capital investments that took place since 1974. In these models we include only the number of granted patents as our measure of patent activity. These results are qualitatively equivalent to the results presented in Tables 2 and 3.

[20] The density of VCFs did not include the funding VCFs of the focal firm.

[21] We employed the general formula of the spherical law of cosines which corrects for Earth's spherical shape: $\text{Distance}_{12} = ar\cos(\sin(\text{lat}_1).\sin(\text{lat}_2)+\cos(\text{lat}_1).\cos(\text{lat}_2).\cos(\text{long}_2-\text{long}_1)) \times 3963$

[22] See http://www.uspto.gov/news/pr/2010/10_22.jsp for an official USPTO press release regarding its cooperation with Google Patents ®. In particular, under this agreement USPTO provided all of its patent documents to Google largely because the latter has the technical capacity to provide patent data in bulk. Compared to other popular databases often used in the literature such as Patstat and the NBER database, since the data source is identical (USPTO), the information provided is in large part comparable. For our purposes, the main advantage of Google Patents ® was the ease of retrieving patent counts and applications by using slightly different names of each company without having to search within one file but rather by connecting to the Google Patents ® interface.

application where the focal firm was listed as the applicant/assignee.[23] Using the application and granted date we allocated patent activity between rounds. To construct *PatentCiteYear_r1*and *PatentCiteYear_r2* we employed Google Patents ® and counted the number of times each of the patents in our dataset was cited by other patents. Then, for each firm we calculated the average number of citations across all granted patents of the firm. As noted in footnote 12, to account for the tendency of older patents to be cited more heavily, we divided the average number of forward citations for the patents of a given firm by the difference (in years) between early summer of 2012 (when the variable was constructed) and the date that the patent was granted.

To collect biographical information for the academic founders we visited the website of each firm and complemented this search with academic founders' biographies provided at their personal websites. Using these sources, firms whose founder(s) had started a firm previously and/or held a distinguished and/or named professorship and/or were a member of the Academy of Sciences and/or had won a Nobel Prize took the value of 1 in the *FounderSignal* dummy variable.

To build *VCFreputation_1* we first consulted the yearly reputation rankings of VCFs maintained at http://www.timothypollock.com/vc_reputation.htm (Lee et al., 2011). DBFs whose funding VCFs at the time of the financing round were not ranked, were coded as 0. DBFs whose highest ranked VCF was also the highest ranked of all VCFs were coded as 1. To illustrate how we calculated our reputation indicator we provide here an example for which the highest rated VCF was ranked as 250th in the year in question. To construct our index we first divide 250 by 1000 (the total number of ranked VCFs) which yields 0.25 and then we subtract 0.25 from 1 to have 0.75, which is the value of the *VCFreputation_1* variable for this hypothetical example. Along the same lines, if the highest rated VCF was ranked 150th, the value of the *VCFreputation_1* variable would be 0.85. And so on.

To construct *UniversitiesInMSA* we used the list of recipient institutions of biotechnology-related research grants maintained at the website of the National Institutes of

[23] In a number of cases the name of the applicant/assignee differed across patents as, for instance, "inc." was missing or it was replaced by "inc". To ensure that the validity of our measure was not prone to such issues we double-checked the number of patents using a number of variations of the name of each firm.

Health. We complemented this list with comparable listings from the Association of University Technology Managers and the Chronicles of Higher Education. All three sources had information on the main address of each institution and whenever information was missing we visited the website of each institution to collect the address. The addresses were then assigned to MSAs using the zip code-to MSA list provided by the U.S. Bureau of Economic Analysis.

Finally, to build *PATENTarea_0010_1, PATENTarea_1020_1, PATENTarea_0010_2,* and *PATENTarea_1020_2* we first visited Google Patents ® to measure the yearly total number of patents assigned to each DBF. Then, we summed over the patents that were granted before each round of financing to DBFs within 0 to 10 and 10 to 20 miles from the origin DBF (using the coordinates and the distance formula previously described).

-----Tables 1a and 1b about here ----

Tables 1a and 1b presents descriptive statistics of the variables used in the empirical models. As described by the modal values of the two dependent variables we use in the analysis, most DBFs in the dataset received $1 million for the first round of financing and $10 million for the second round of financing.[24] Note that the standard deviation is larger than the mean observed value which indicates the wide array of venture capital amounts invested in different firms. Most firms did not have any patent activity before the focal round of financing, but the standard deviation of the observed patenting activity surpasses the average of the observed values and suggests that some firms had a large number of patents and patent applications before the focal round of financing. This is an important observation because it indicates that our sample is composed of firms with varying degrees of patent activity and thus it alleviates concerns of overstressing the significance of patents that might result from the potential tendency of better firms to patent more and better protect their intellectual property

[24] As seen in Tables 1a and 1b the minimum value for the amount raised for a given firm in our sample is below $10,000, which, especially in biotechnology, is uncommon. We verified this amount with our data source but to ensure that a potential misreporting would not affect our estimates we run the baseline regression omitting the amount at hand and reached almost identical results.

assets (Helmers and Rogers, 2011).[25] The majority of the patents granted to firms in our sample did not receive any citations per year.

Most of the firms in the dataset were close to four months (0 years in Table 1a) and two years old when they received first and second round of financing which were mostly directed to the seed and startup stage respectively.[26] The average reputation score for the highest ranked funding VCF in either round was 0.37 which translates to a yearly ranking of 630 out of 1000.[27] One hundred and nineteen firms in the first round dataset had a founder that was coded as conveying a signal of quality (the corresponding value for firms that went to the second round was 101). For half of the firms in either round the closest funding VCF was located within about 20 miles distance from the firm. DBFs received funds mostly from 1 VCF both in the first and the second round of financing and the average number of investors for the first and the second round of financing was 2.6 and 3, respectively. With regard to the size of the investors, on average, they had invested around 367 million before providing first round financing to the firm and 438 million before providing second round financing to the firm.

With respect to the regional environment of the average focal firm, around 9 universities were located in the same MSA, roughly 24 VCFs were located in a 0 to 10 miles

[25] In a similar vein, an alternative explanation could be that larger firms patent more. To check this argument we used LexisNexis Academics, Business Insights: Essentials and Business Source Premier to assess the size distribution, via employee counts, of the DBFs in our dataset at the time they received the focal round of financing. But, employee counts for the specific point in time in which a particular DBF received the venture capital investment were difficult to source. Nevertheless, the statistics for the 196 DBFs that we could find their number of employees at the timing of round 1 indicate that 150 DBFs (or 76.5 percent of the 196 firms) had less than 25 employees. In fact, the standard deviation of the variable in question was below the average, the modal value was 3 and 96 firms had less than 10 employees. In all, these statistics suggest that our sample is relatively homogeneous in terms of firm size. This is a relevant consideration because it implies that the growth of venture capital funds in our sample is not primarily driven by firm size. Further note that we searched for the size of the firms at round 1 because the time span between rounds in the dataset was relatively short implying that firm size between rounds did not change drastically. More specifically, the average time between round 1 and round 2 was 13 months with a standard deviation of 10 months and a modal value of 7 months. Interestingly, this homogeneous distribution in terms of time span between rounds is particularly relevant for the estimates of round 2 because it indicates that the effective time for the reduction of information asymmetries between VCFs and DBFs is relatively similar across firms. As such, potential differences in the reduction of information asymmetries that may result from different time spans between rounds do not appear to raise significant concerns.

[26] Note that the relatively uniform age in which the sample firms receive their first round of financing alleviates concerns that maybe better firms (or/and those that better protect their intellectual property) in the dataset did not necessarily receive the most funds during that round but they did receive them faster (Hsu and Ziedonis, 2013 page 772).

[27] 1-(630/1000)=0.37

radius and approximately 15 VCFs in a 10 to 20 miles radius. Further, in information not reported in Tables 1a and 1b, we note that our dataset draws from both urban and rural areas. Finally, the average DBF in our sample was surrounded by DBFs that in sum had been granted around 200 patents before the focal DBF received funds (approximately 130 patents were granted to firms in a 0 to 10 miles distance and roughly 70 patents were granted to firms in a 10 to 20 miles distance).

5. Empirical results

5.1 The Impact of Patent Activity on Venture Capital Financing

Tables 2 and 3 present the estimated coefficients for the models described in section 3. First we report the heteroskedasticity robust standard errors and the associated significance levels and in the last two columns of Tables 2 and 3 we report the corresponding information for standard errors clustered at the state level. The statistical inferences from the two sets of standard errors are nearly identical (the coefficients are by definition the same) and hence the models are robust to these alternative specifications.

The fit statistics reported at the bottom of those Tables indicate the joint significance of the variables in the empirical models and suggest that the fitted models have explanatory power. Finally, the multicollinearity condition index (13.36 and 13.40 for each model) is within limits and do not raise concerns about the presence of multicollinearity (Greene, 2003). Nevertheless, as part of our robustness checks, in section 5.2 we present regressions with only a limited number of regressors where the multicollinearity index is lower and still find qualitatively similar results. Relatedly, as shown in the correlation tables presented in Appendix Tables l and 2, the correlation coefficient among the granted patents before round 1 and the granted patents after round 1 is inflated (0.78).[28] Accordingly, the separate impact of each variable in the model of round 2 may be difficult to measure due to such correlation. In section 5.2 we present models

[28] This correlation coefficient is inflated by a single firm which has 20 granted patents in round 1 and 22 granted patents in round 2. When we exclude this firm from the sample the correlation coefficient drops drastically to 0.28. As well, excluding this firm from the analysis does not impact the baseline estimates in any material way.

where the patent activity measures of round 1 are omitted from the analysis and reach similar conclusion to the baseline estimates of Tables 2 and 3.

-----Tables 2 and 3 about here ----

Because the dependent variable is in logarithmic form, the estimated coefficients can be interpreted as semi-elasticities. In line with theoretical expectations, we fail to reject the hypothesis that patents act as a signal that attracts venture capital investments for the first round of investment and have a diminished effect for the second round of investment.[29] In particular, one additional patent application before the first round of financing increases the amount of funds raised by a firm by 7.7 percent. This is a considerable increase especially when considering the 0 modal value for the *PATENTApp_1* variable and suggests that firms without patent activity generally receive significantly less funding from VCFs. To put the magnitude of the estimated coefficient in perspective, when evaluated at the average amount of first round funds observed in the sample (Table 1a) the estimated coefficient indicates that one additional patent application increases venture capital investments by $557,333[30] when the modal value of the first round of financing is $1,000,000. When compared to the direct costs of obtaining a patent, which typically range between $10,000 and $38,000 (Graham et al., 2009; Lemley, 2000), the estimated signaling value of such a patent far surpasses these direct costs. While this comparison is not meant to be a cost-benefit ratio for the acquisition of patents by DBFs, our empirical results strongly suggest that the signaling value of patenting activity is very significant and should be explicitly accounted for when firm strategy and public policy consider the usefulness of patents.

Patent activity does not appear to attract higher amounts of second round venture capital investments, implying that a reduction of information asymmetries between investors and target firms leads to a decrease in the signaling value of patent activity. Notably, patent activity before

[29] Technically, as an anonymous reviewer correctly points out, similar to a large body of empirical literature in a number of domains we cannot accept the hypothesis: by research design while we control for a type I error (wrongly rejecting the null hypothesis) we cannot control for a type II error (wrongly accepting the null hypothesis that patent activity has no effect in the second round).

[30] 0.0773*7.21M (the average amount of first round funds reported in Table 1a)=557,333

the first round of financing influences only the first round of financing funds and patent activity after the first round of financing does not influence the amount of funds raised in the second round. These findings are in line with Hypothesis 1 and, importantly, indicate that patent activity carries a significant signaling value that diminishes once the hidden quality of a given firm is better assessed by the investors. Our empirical results also suggest that while patent applications play an important signaling role, the granted patents of a focal firm do not appear to attract additional funds either in the first or in the second round of financing. This result is consistent with previous findings (Baum and Silverman, 2004; Häussler et al., 2009) and it likely suggests that because patent applications may be stronger in conveying a firm that does not sit idle they are seen more favorably by investors.[31] Interestingly, patents of higher economic value, as proxied by forward patent citations, did not appear to prompt VCFs towards larger investments either in round 1 or in round 2.[32]

The coefficient of the *GrowthStage_1* variable indicates that when the first round of financing occurs at later stages of firm development, the amount invested by VCFs increases considerably. Hence, this indicator seems to capture effectively the elevated financial inflows needed for later stage investments. The coefficient of the *GrowthStage_2* for round 2 financing is not statistically significant, however.

Similar to the diminishing signaling value of patent activity, the founder signal significantly improved only the level of the first round of financing, when information asymmetries are prevalent. The reputation of the first round investors did not influence the level of funding in the second round of investment for the DBFs in our sample. Indeed, most of the firms received funds from a single investor (Tables 1a and 1b), who in most cases was the

[31] We note however, that the joint significance test of granted patents and patent applications suggests that patent activity influences the first round of investment but not the second. Therefore, while *per se* granted patents may not exert a significant influence on venture capital attraction, when considered in conjunction with applications, they matter for the first round of investment.

[32] In unreported models where the *GrowthStage* variables are not included in the analysis, the forward citations variable is statistically significant for round 1. Therefore, it appears that VCFs are attracted to patents that may yield higher returns (i.e. higher quality patents) but such effect lessens once calculations about the *ex-ante* valuation of the firm come in place. Note that such finding can be informative for the relevance of forward citations as a measure of economic patent value.

main investor in the second round as well. As such, our finding may reflect this funding structure in our sample.

Our results on the influence of the syndication of investors are in line with theoretical expectations and recent literature findings (Tian, 2011). In particular, we find that investments by large groups of wealthy syndicated VCFs are associated with higher levels of capital investments in a given firm. In fact, for the second round of financing the characteristics of the funding VCFs are prime determinants of the venture capital funds invested in a given firm. Finally, we find that firms funded by closely located VCFs receive, on average, less per round of financing. One additional mile in the distance between the target firm and the closest investor increases the total amount of financing by approximately 0.03 percent.[33]

The density of VCFs and patents in a 10 mile radius positively influences only the first round level of financing and not the second. We find these results particularly interesting because proximity effects appear to matter when firms are younger and less so when firms are more developed and experienced; a finding that sides with previous evidence that less established firms tend to benefit the most from proximity effects (McCann and Folta, 2011). These results imply that DBFs in early stages of development benefit from proximity effects but as they mature, performance benefits from access to local knowledge are not as pronounced. Finally, the density of universities in an MSA does not appear to influence the accumulation of venture capital funds of DBFs in the region in either round of financing.

Our control variables indicate that older firms receive more funds at the first round of financing and that year to year variations have only limited explanatory power in the amount of venture capital funds raised by firms. Similarly, the interaction term included in the analysis (granted patents * universities in the MSA) was not a statistically significant regressor.

[33] This result is shaped, in some part, by the geographic distribution of VCFs and DBFs in our sample. Most of the firms in our sample source funds from VCFs located within walking distance and half of the firms receive funds from VCFs located less than 20 miles away (Tables 1a and 1b). As such, the average distance between target firms and VCFs reported in Tables 1a and 1b (398 and 345 per round) is inflated somewhat by a small number of observations where East/West coast VCFs fund West/East coast DBFs in which typically larger VCFs provided significant amounts of finance to target firms across the country. Consequently, while statistically significant, the effect of the *DistanceClosestVCF* is expected to have a small overall economic effect for the majority of firms in our sample.

5.2 Robustness Checks

To check the robustness of our results we construct a number of additional models whose results we present in Table 4.

-----Table 4 about here ----

Our main estimates rely on a sample of firms that received venture capital investments. But if these firms were more likely to receive funds from other firms in the first place, then our estimates could suffer from selection bias. Along the same lines, for the empirical model of round 2, we focus the analysis on firms that received such funds but if these firms differ from remaining firms, the estimates, again, could be biased. To address these issues we construct two Heckman selection models where for the model of round 1 in the first stage we model the probability that a firm receives venture capital and in the second stage we conduct the baseline analysis. In the selection model for round 2, we first model the probability that a firm receives second round financing and then analyze the factors that influence the amount it receives in that round. In the set of regressors we include variables such as patents, founder's status and receipt of government grants that have been previously shown to affect the chances of receiving venture capital and to influence the chances a firm receives second round investment (Kaplan and Strömberg, 2004; Lerner, 1999; MacMillan et al., 1986). To source the sample of firms that had not received venture capital funds we relied on proprietary data from InKnowVation reflecting all biotechnology firms that had won grants from the Small Business Innovation Research (SBIR) program from 1983 to 2006.[34] The dataset included firm-specific information such as patents and year of foundation as well as an indicator of whether or not the SBIR winner firms had received venture capital investments, with the majority of those firms not having

[34] The dataset included all life science winners. In order to identify the biotechnology firms we performed a keyword search on the business description of all the firms. The list of biotechnology keywords was constructed after consulting with biotechnology researchers employed at the authors' institutions and included almost 400 keywords with about 100 of them characterizing the vast majority of the firms in the dataset (Kolympiris et al., 2014). These keywords included glycosylation, oligo-nucleotide, mutation, antigen, recombinant allergens, biofiltration, glycosylation, Bacillus thuringiensis, polymerase chain reaction (PCR), chondrocyte differentiation, biosynthesis, recombinant enzymes, genetic engineering, stem cells, bioprocessing, genetic, biotic stress, genetic parameters, chimeraplasty, introgression, biomedicine, reverse transcriptase, glycoprotein, directional cloning, western blot, combinatorial biocatalysis, arabidopsis, gene (DNA) sequencing.

received funds from VCFs.[35] As shown in Models 1 and 2 of Table 4, the results remain nearly identical in magnitude, sign and statistical significance to our baseline estimates of Tables 2 and 3 and indicate that any potential selection bias does not materially change our estimates.

Our analysis uses data from 2001 to 2011 because it is in this period that both granted patents and patent application statistics are available from USPTO (granted patents are available for earlier years). Nevertheless, focusing solely on that period may mask differential effects that took place on earlier periods. Given that our data source on venture capital investments goes back to 1974, in Models 3 and 4 of Table 4 we present the results of empirical specifications that include only granted patents as the measure of patent activity and include observations that reflect investments that took place from 1974 to 2011 inclusive. Importantly, these specifications do not directly test our hypotheses because only one of the two patent activity measures we employ is, by definition, available. The goal of these specifications is to check whether the insignificance of the granted patents variables holds when we extend the period of analysis. Indeed, in accordance with the main results presented in Tables 1 and 2, granted patents have no effect neither on the first round investment level nor on the second round investment level. As well, inferences from the remaining regressors are similar to those in the baseline results.

As seen in Tables 1a and 1b a small cohort of firms had a number of patents and patent applications that surpassed the average patent activity of the firms in the dataset. In Models 5

[35] Instead of using the age variable in the first stage of the Heckman model we use the year of foundation. We do so because for the age variable to be meaningful in our application we need to model the probability that a firm receives venture capital investment within a specific period of time. However, by definition, such period of time does not exist for firms that did not receive venture capital investments. More to the list of variables we use for the selection equation, we employ only granted patents as our measure of patent activity in the first stage because a number of recipient firms received the award before 2001 and as such the full list of submitted applications is not available from the USPTO (and hence from our data source, InKnowVation). The selection of the remaining variables we employ to construct the first stage of the Heckman model is guided, primarily, by findings of previous literature. To illustrate, for the round 1 selection equation we include the SBIR and the location dummies based on the findings that a. SBIR winners are more likely to attract venture capital funds (Lerner, 1999) and b. that firms located in Massachusetts or California are more likely to attract funds (Lerner, 1999). The relationship of those factors with the amount of venture capital raised in the first round has not been replicated in the existing literature. As such, we consider these factors as relevant for the first and not for the second stage of the Heckman model. Factors for which empirical evidence is scarce but we theorize are relevant for both stages (e.g. *FounderSignal*) are included in both stages. Finally, note that even when different groups of variables are included in the selection equation, the results remain largely unchanged.

and 6 we test how these outlier observations impact our baseline results by re-estimating the models of Tables 2 and 3 using data that omits these observations from the analysis.[36] By and large, the results agree with the estimates of Tables 2 and 3 that patent activity carries a signaling value that diminishes once the hidden quality of the DBFs is better approximated by the VCFs. A noteworthy result though is that the coefficient of the *PatentApp_1* variable doubles in magnitude. We find this result particularly interesting because it implies that for firms with average patent activity the signaling value of patent applications is even more pronounced than the corresponding value for emerging DBFs with above average patent activity.

In Model 7 we pooled the data for the first and the second round together to construct a pooled regression model that controls for firm and year fixed effects. The dependent variable in that model is the amount raised in a given investment round and the right-hand side variables are round-specific. Then, we include a dummy variable that takes the value of 1 if the observation corresponds to first round investment and 0 otherwise. To test for the impact of patent activity on venture capital growth we add an interaction term that is the product of the number of patent applications and the dummy variable previously described.[37] The marginal effect of *PatentApp_1*[38] indicates that patent activity is conducive to the increase of funds for the first round and negatively affects the level of the second round funds. This result suggests that unobserved firm-specific time constant features can determine whether the overall trend of patent activity serving a signaling role that diminishes over time holds for a specific firm.

[36] Specifically, for the model of round 1 we omitted 4 firms that had more than 10 patent applications before round 1. These same firms were omitted from the analysis of round 2. Additionally, for round 2, we omitted 5 firms that had 10 or more patent applications between the two rounds. Therefore, in total we omitted 9 firms from the analysis. The results remained nearly identical even when we omitted firms with more than 5 patent applications.

[37] We also interact the round 1 dummy with granted patents but the corresponding coefficient is not statistically significant. We do not include that interaction term in the analysis because the multicollinearity index of the model including both interaction terms increases to levels that create inference concerns.

[38] The marginal effect is the first derivative of the amount of funds raised with respect to the number of patent applications. Employing the estimated coefficients, the marginal effect of patent applications can then be calculated as -0.2388 * D - 0.0459 + 0.0896 * D where D equals 1 for observations in the first round and 0 otherwise.

To test the robustness of our estimates to the elevated correlation coefficient between the two variables that measure granted patents between rounds, in Models 8 and 9 we present estimates from i) a model that includes only patent activity measures after round 1 and ii) a model that includes only the two variables that are correlated (*PatentGrant_1* and *PatentGrant_2*). Along the same lines, in models 10 and 11 we test whether the influence of the control variables is sensitive to the inclusion of the patent activity measures by constructing round 1 and round 2 models that include only the control variables. We draw two main conclusions from models 8 to 11. First, the influence of the control variables remains largely unchanged regardless of the inclusion of the patent activity variables. Second, the patent activity variables do not appear to be significantly affected by the correlation in question. Accordingly, we conclude that our main findings in the baseline models are robust.

Finally, to test the sensitivity of our estimates to the (economic) patent value indicator we use in the baseline estimates, in Models 12 and 13 we replace the forward citations variables with variables that measure the average INPADOC[39] family size of each patent owned by the focal firms. Patents in the same patent family typically protect the same (set of) invention(s) in different jurisdictions. Patents that are then part of broad patent families are expected to have a higher economic value as the applicant has chosen to accrue additional costs for protection in multiple jurisdictions (Fischer and Leidinger, 2013; Harhoff et al., 2003; Lanjouw et al., 1998). The results in Models 12 and 13 are nearly identical to the baseline estimates and show that under alternative proxies of economic patent value our main conclusions remain intact.

6. Conclusion and discussion

A long stream of research has documented the positive effects that patents bring about to firms. The general consensus is that patents contribute to firm growth and survival because they confer monopolistic market rights, offer protection from competitors and enhance the

[39] INPADOC, which stands for International Patent Documentation Center, is a patent information database that is maintained by the European Patent Office and contains cross-referenced data on patents gathered from national patent offices worldwide. The data to construct the variable were obtained from Thomson Innovation.

negotiating position of patent holders. What has received relatively less attention in this literature is that patents can act as a signal to attract investors and capital. These types of effects are particularly important to emerging firms in knowledge intensive industries where long research cycles, scientific complexities and strict regulatory regimes make the development of a track record for newly established firms difficult. In this context, signals that convey firm potential and quality can be particularly relevant. A handful of empirical studies that have taken up the issue in the past have shown that knowledge intensive firms which hold granted patents or have patent applications are more likely to receive larger venture capital investments faster. Out of these studies only few have demonstrated that the reported results reflect signaling effects and only one has indicated that such signaling effects wane with time. As such, the dynamics of signaling effects have not been investigated in any significant depth, and little is known about whether the signaling function of patents diminishes over time. In this study, we shed new light on the signaling function of patents in attracting investors by examining the strength of the signaling effects of patent activity in sequential rounds of financing for small biotechnology firms. By extension, the overarching contribution of the present study is to be among the first to study the dynamics of signals.

Employing data from more than 580 U.S.-based dedicated biotechnology firms, we examine whether the patent activity (granted patents and patent applications) of small biotechnology firms increases the amount of venture capital funds raised by such firms during their first and second round of financing. Our empirical results strongly corroborate theoretical expectations that patent activity before the first round of financing increases the capital invested in a firm. However, as firms mature and information asymmetries between them and investors decrease, the signaling value of patent activity diminishes and it does not affect the level of funds raised in the second round of financing. We also find that patent applications rather than granted patents have a more significant signaling role. This finding potentially reflects the notion that patent applications offer a stronger signal than patents perhaps because they convey information that young emerging firms are further developing due to the learning curve associated with the patent acquisition process. Investments that are directed towards later firm

growth stages are also associated with higher amounts of capital investments. Finally, we find that the amount of venture capital funds raised by small biotech firms is also influenced by certain characteristics of the investors, such as size and syndication, as well as by proximity effects that allow firms to source knowledge from nearby institutions.

Our study has both scholarly and policy implications. For instance, we quantify the signaling value of patent activity and we find that, on average, an additional patent application is associated with an increase of approximately $557,333 in the amount of venture capital funds raised in the first round of financing by small biotech firms. This estimate is generally robust to various model specifications that address potential bias that can result from focusing solely on firms that receive venture capital investments and to alternative empirical designs. Importantly, this $557,333 valuation complements existing studies which estimate the value of patents but do not take into account the value of their signaling effect in attracting capital (Gambardella et al., 2008). The same finding however, has also important policy implications. Concerns have been frequently raised about the current status of the patenting system and about the degree it might hinder innovation, especially by placing young innovative firms at a disadvantage (Kingston, 2001). Our findings, however, suggest that the signaling value of patent activity not only exceeds the typical direct costs of patent acquisition manifold but it can also improve the access of small innovative firms to capital during early stages of financing, exactly when such firms lack a track record and information about their potential is less available. It is therefore clear, that any discussion about the value of patents for small innovative firms and for firm strategy should include such considerations. More specifically, the case can be made that due to the signaling value of patent activity, emerging firms who opt out of using it may be more inclined to reconsider their strategy. Accordingly, if these kinds of firms are fetched back to the patent system they could provide additional income to the patent authorities which could then potentially address common patent system issues such as backlogging of applications via hiring qualified examiners, providing employee bonuses and the like.

Given these policy and firm-specific implications, of direct interest is then the applicability of our results to industries other than biotechnology and to countries other than the

US. With regard to applicability to other industries, we generally expect our findings to hold for emerging firms in industries that, like biotechnology, are prone to information asymmetries due to long research or development cycles with uncertain research and commercial outcomes that make quality signals useful. To corroborate these expectations, indeed, there is some limited empirical evidence suggesting that patents are positively associated with increases in venture capital in a number of such industries (Cao and Hsu, 2011) and in some countries outside the US (Baum and Silverman, 2004; Engel and Keilbach, 2007).

There are several ways that our work can be extended. First, in depth analysis of the dynamics of signals, not confined to patents, seems promising especially given the dearth of research on the topic (Higgins et al., 2011). Such research can, for instance, analyze the factors that influence the strength and effectiveness of signals. These factors include transmission mechanisms and the *a priori* credibility of the signal transmitter. Second, a straightforward extension of the present work would be to track the growth of the firms who successfully transmit signals in order to evaluate the long term effects of signaling. Third, a potentially qualitative analysis could directly identify the firm-specific factors that can influence how strong is the overall trend of the diminishing signaling value of patents for a given firm. Fourth, the dynamics of proximity effects on capital investment uncovered in this study may be worth further attention. Proximity effects were found to have a positive impact on the venture capital funds of small biotech firms only during the first round of financing when firms were in the early stages of development. It is therefore possible that knowledge spillovers from agglomeration and associated pecuniary effects may be stronger for smaller firms early in their innovation cycle. Such dynamic effects are not broadly researched in the agglomeration literature and it may be a worthwhile follow-up research topic.

To conclude, we note that our study is not without limitations. For instance, to account for the venture capital funds provided to a firm in exchange of equity in the firm we employ a variable that reflects the firm growth stage that venture capital funds are directed to and a variable that reflects the reputation of the investors. While we expect these variables to indeed be suitable proxies, data limitations do not allow us to use sharper measures such as the actual

equity level secured by the investors, which could yield more refined estimates. Along the same lines, assessing proprietary firm-specific information about (unsuccessful) patent applications before 2001 could provide further insights by expanding the time period of the analysis. Finally, based on a large body of empirical work we employ forward citations and patent family size to capture the economic value of patents. However, by design, proxies are imperfect measures. As such, it is possible that the economic value of a given patent is not fully accounted for in our models. Direct inquires to the venture capital firms we study with regard to the economic value they ascribed to the sample patents would address the issue. But, such endeavor is prohibitively difficult in large part because a significant part of the investments we study took place more than a decade ago.

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Table 1a

Table 1a. Descriptive Statistics of Selected Variables Used in the Empirical Models for the First Round of Financing

Variable Description	Variable code	OBS	MEAN	MEDIAN	MODE	STD. DEV	MIN.	MAX.
The size of the first round of venture capital funds (1,000,000 USD)	USD_R1	586	7.21	3.56	1.00	11.04	0.00	100.00
Number of patent applications filed by a biotechnology firm from foundation to the first round of investment[1]	PATENTApp_1	586	0.29	0.00	0.00	1.30	0.00	15.00
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment[1]	PATENTGrant_1	586	0.19	0.00	0.00	1.44	0.00	22.00
Average number of forward patent citations per year of patents granted between firm foundation and the first round of investment	PATENTCiteYear_1	586	0.06	0.00	0.00	0.44	0.00	6.83
Variable that assumes increasing values for investments directed towards later stages of firm growth for first round investments[2]	GrowthStage_1	**D:0**	**D:1**	**D:2**	**D:3**	**D:4**		
		12	248	246	78	2		
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment[3]	VCFReputation_1	586	0.00	0.00	0.45	0.00	0.00	1.00
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms[4]	FounderSignal	119						
Number of venture capital firms participating in the first round of investment	SyndicateInvestors_1	586	2.61	2.00	1.00	1.84	1.00	13.00
Average sum the funding venture capital firms had invested prior to investing in the focal firm for the first round of investment ($1,000,000)	SyndicateSize_1	586	367.01	75.47	0.00	616.60	0.00	4155.00
Distance of the focal firm to the closest funding participating venture capital firm (miles)	DistanceClosestVCF	586	398.49	20.63	0.01	747.92	0.00	3146.00
Total number of universities located in the focal firm's Metropolitan Statistical Area	UniversitiesInMSA	586	9.29	9.00	17.00	8.09	0.00	37.00
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the first round of investment	VCFarea_0010_1	586	23.34	10.00	1.00	29.36	0.00	103.00
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the first round of investment	VCFarea_1020_1	586	15.21	5.00	0.00	25.37	0.00	127.00
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the first round of investment	PATENTArea_0010_1	586	126.55	61.00	0.00	155.87	0.00	531.00
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the first round of investment	PATENTArea_1020_1	586	69.73	18.00	0.00	115.16	0.00	608.00
Age of a biotechnology firm from foundation to the first round of investment (years)	AGE1	586	2.54	1.37	0.00	3.12	0.00	27.00

[1]By definition the number of applications needs to be greater or equal to the number of granted patents for a given firm. The reason why the maximum value of granted patents is greater than the maximum value for patent applications is twofold: First, the values refer to different firms. Second, as Appendix Figure 1 illustrates, to avoid double-counting PatentApp_1 measures only applications that were not granted patent rights before the first round ; that is we exclude applications whose grant we include in the PatentGrant_1 variable. Therefore, the number of granted patents may be greater than the number of applications if for instance the filing and the grant date of the patent are both before the date of the first round.

[2]The variable takes the value of 1 if the investment was categorized as "Seed Stage", 2 if the investment was categorized as "Early Stage", 3 if the investment was categorized as "Expansion Stage", 4 if the investment was categorized "Later Stage", "Buy-Out" or "Acquisition". We code as 0 observations that correspond to other stages, mostly what is reported in our data source as "Pipe". The boxes indicate the number of observations for each round that correspond to each of the 5 categories

[3]The index takes the value of 0 if the participating VCFs are unranked. When participating VCFs are ranked in the the Lee-Pollock-Jin VC Reputation index (Lee, Pollock et al. 2011), the value lies between 1 (when the VCF is rank 1) and 0.001 (when the VCF is the lowest ranked VCF in the list).

[4]In the case of the *FounderSignal* variable the figure measures the number biotechnology firms with the founder matching the said characteristics

Note: 64 observations in 2001, 59 observations in 2002, 52 observations in 2003, 50 observations in 2004, 66 observations in 2005, 74 observations in 2006, 78 observations in 2007, 63 observations in 2008, 33 observations in 2009, 39 observations in 2010 and 8 observations in 2011

Table 1b

Table 1b. Descriptive Statistics of Selected Variables Used in the Empirical Models for the Second Round of Financing

Variable Description	Variable code	OBS	MEAN	MEDIAN	MODE	STD. DEV	MIN.	MAX.
The size of the first round of venture capital funds (1,000,000 USD)	USD_R1	494	6.86	3.10	1.00	11.07	0.00	100.00
The size of the second round of venture capital funds (1,000,000 USD)	USD_R2	494	8.00	4.32	10.00	9.94	0.02	87.00
Number of patent applications filed by a biotechnology firm from foundation to the first round of investment[1]	PATENTApp_1	494	0.18	0.00	0.00	1.10	0.00	13.00
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment[1]	PATENTGrant_1	494	0.12	0.00	0.00	1.03	0.00	20.00
Number of patent applications filed by a biotechnology firm from the first round of investment to the second round of investment[1]	PATENTApp_2	494	0.40	0.00	0.00	1.49	0.00	18.00
Number of patents granted to a biotechnology firm from the first round of investment to the second round of investment[1]	PATENTGrant_2	494	0.22	0.00	0.00	1.24	0.00	22.00
Average number of forward patent citations per year of patents granted between firm foundation and the first round of investment	PATENTCiteYear_1	494	0.00	0.00	0.44	0.00	0.00	6.83
Average number of forward patent citations per year of patents granted between the first round of investment and the second round of investment	PATENTCiteYear_2	494	0.08	0.00	0.00	0.56	0.00	9.17
Variable that assumes increasing values for investments directed towards later stages of firm growth for second round investments[2]	GrowthStage_2	**D:0**	**D:1**	**D:2**	**D:3**	**D:4**		
		30	103	213	148	0		
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment[3]	VCFReputation_1	494	0.37	0.00	0.00	0.45	0.00	1.00
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms[4]	FounderSignal	101						
Number of venture capital firms participating in the second round of investment	SyndicateInvestors_2	494	3.01	2.00	1.00	2.19	1.00	15.00
Average sum the funding venture capital firms had invested prior to investing in the focal firm for the second round of investment ($1,000,000)	SyndicateSize_2	494	438.17	138.17	0.00	624.23	0.00	3816.43
Distance of the focal firm to the closest funding participating venture capital firm (miles)	DistanceClosestVCF	494	345.00	20.42	0.50	686.22	0.00	3146.00
Total number of universities located in the focal firm's Metropolitan Statistical Area	UniversitiesInMSA	494	9.28	8.00	17.00	8.24	0.00	37.00
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the second round of investment	VCFarea_0010_2	494	24.12	11.00	0.00	30.04	0.00	103.00
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the second round of investment	VCFarea_1020_2	494	15.51	5.00	0.00	26.61	0.00	127.00
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the second round of investment	PATENTarea_0010_2	494	133.72	64.00	0.00	162.06	0.00	535.00
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the second round of investment	PATENTarea_1020_2	494	72.04	21.00	0.00	118.63	0.00	613.00
Age of a biotechnology firm from foundation to the second round of investment (years)	AGE2	494	3.34	2.41	2.00	3.08	0.00	28.89

[1]By definition the number of applications needs to be greater or equal to the number of granted patents for a given firm. The reason why the maximum value of granted patents is greater than the maximum value for patent applications is twofold: First, the values refer to different firms. Second, as Appendix Figure 1 illustrates, to avoid double-counting PatentApp_1 measures only applications that were not granted patent rights between the first and the second round ; that is we exclude applications whose grant we include in the PatentGrant_1 and PatentGrant_2 variable. Therefore, the number of granted patents may be greater than the number of applications if for instance the filing and the grant date of the patent are both between the dates of the first and the second round.

[2]The variable takes the value of 1 if the investment was categorized as "Seed Stage", 2 if the investment was categorized as "Early Stage", 3 if the investment was categorized as "Expansion Stage", 4 if the investment was categorized "Later Stage", "Buy-Out" or "Acquisition". We code as 0 observations that correspond to other stages, mostly what is reported in our data source as "Pipe". The boxes indicate the number of observations for each round that correspond to each of the 5 categories

[3]The index takes the value of 0 if the participating VCFs are unranked. When participating VCFs are ranked in the the Lee-Pollock-Jin VC Reputation index (Lee, Pollock et al. 2011), the value lies between 1 (when the VCF is rank 1) and 0.001 (when the VCF is the lowest ranked VCF in the list).

[4]In the case of the *FounderSignal* variable the figure measures the number biotechnology firms with the founder matching the said characteristics

Note: 57 observations in 2001, 51 observations in 2002, 44 observations in 2003, 44 observations in 2004, 59 observations in 2005, 68 observations in 2006, 72 observations in 2007, 55 observations in 2008, 23 observations in 2009 and 21 observations in 2010.

Table 2

Table 2. Estimated coefficients for the model of the first round of financing. The Dependent Variable is the natural log of the amount of venture capital funds invested by a biotechnology firm for the first round of financing.

Variable Description	Variable code	Coefficient	Heteroskedasticity robust standard errors	Standard errors clustered at the state level
	Intercept	12.2816	0.2606 ***	0.4155 ***
Number of patent applications filed by a biotechnology firm from foundation to the first round of investment	PATENTApp_1	0.0773	0.0302 **	0.0289 ***
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment	PATENTGrant_1	-0.0675	0.0534	0.0510
Average number of forward patent citations per year of patents granted between firm foundation and the first round of investment	PATENTCiteYear_1	-0.0700	0.0738	0.0858
Variable that assumes increasing values for investments directed towards later stages of firm growth	GrowthStage_1	0.3609	0.0967 ***	0.0761 ***
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment	VCFReputation_1	0.2323	0.1277	0.1648
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms	FounderSignal	0.4516	0.1364 ***	0.1182 ***
Number of venture capital firms participating in the first round of investment	SyndicateInvestors_1	0.3876	0.0371 ***	0.0552 ***
Average sum the funding venture capital firms had invested prior to investing in the focal firm for the first round of investment ($1,000,000)	SyndicateSize_1	0.0003	0.0001 ***	0.0002
Distance of the focal firm to the closest funding participating venture capital firm (miles)	DistanceClosestVCF	0.0004	0.0001 ***	0.0001 ***
Total number of universities located in the focal firm's Metropolitan Statistical Area	UniversitiesInMSA	0.0017	0.0080	0.0101
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the first round of investment	VCFarea_0010_1	0.0084	0.0023 ***	0.0029 ***
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the first round of investment	VCFarea_1020_1	0.0029	0.0028	0.0032
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the first round of investment	PATENTarea_0010_1	0.0008	0.0004 **	0.0004
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the first round of investment	PATENTarea_1020_1	-0.0002	0.0007	0.0007
Age of a biotechnology firm from foundation to the first round of investment (years)	AGE1	0.0771	0.0226 ***	0.0225 ***
Interaction term: patents granted before round 1 * universities in the MSA	INTERACTION_1	-0.0051	0.0123	0.0075
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2011	YearDummy_2011	-0.2976	0.6102	0.60
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2010	YearDummy_2010	-0.1793	0.2806	0.27
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2009	YearDummy_2009	-0.4815	0.3672	0.26
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2008	YearDummy_2008	0.0323	0.2481	0.21
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2006	YearDummy_2006	-0.1697	0.2367	0.18
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2005	YearDummy_2005	-0.6100	0.2418 **	0.23 ***
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2004	YearDummy_2004	-0.0912	0.2351	0.17
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2003	YearDummy_2003	-0.0986	0.2229	0.17
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2002	YearDummy_2002	0.1789	0.2355	0.17
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2001	YearDummy_2001	0.2768	0.2139	0.21
	R^2	0.4127		
	Adjusted R^2	0.3854		
	F-test for overall model significance		15.26 ***	119.57 ***
	Multicollinearity Condition Number	13.36		
	X^2 for Breusch-Pagan test for heteroskedasticity	13.8 ***		
	Join test of significance PatentApp_1 & PATENTGrant_1	3.66 ***		
	Number of observations	586		

The ommitted year is 2007

Table 3

Table 3. Estimated coefficients for the model of the second round of financing. The Dependent Variable is the natural log of the amount of venture capital funds invested by a biotechnology firm for the second round of financing.

Variable Description	Variable code	Coefficient	Heteroskedasticity robust standard errors	Standard errors clustered at the state level
	Intercept	13.1081	0.2587 ***	0.2865 ***
Number of patent applications filed by a biotechnology firm from foundation to the first round of investment	PATENTApp_1	0.0262	0.0579	0.0564
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment	PATENTGrant_1	0.0533	0.0951	0.1144
Number of patent applications filed by a biotechnology firm from the first round of investment to the second round of investment	PATENTApp_2	-0.0010	0.0349	0.0266
Number of patents granted to a biotechnology firm from the first round of investment to the second round of investment	PATENTGrant_2	0.0083	0.0944	0.1058
Average number of forward patent citations per year of patents granted between firm foundation and the first round of investment	PATENTCiteYear_1	-0.1139	0.0836	0.0827
Average number of forward patent citations per year of patents granted between the first round of investment and the second round of investment	PATENTCiteYear_2	0.0714	0.0506	0.0638
Total amount of venture capital funded to a biotechnology firm for the first round of investment ($1,000,000)	VCF_Investment_1	0.0268	0.0067 ***	0.0070 ***
Variable that assumes increasing values for investments directed towards later stages of firm growth	GrowthStage_2	0.0329	0.0710	0.0582
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment	VCFReputation_1	0.0533	0.1376	0.1306
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms	FounderSignal	0.2414	0.1465	0.1799
Number of venture capital firms participating in the second round of investment	SyndicateInvestors_2	0.3310	0.0286 ***	0.0392 ***
Average sum the funding venture capital firms had invested prior to investing in the focal firm for the second round of investment ($1,000,000)	SyndicateSize_2	0.0006	0.0001 ***	0.0001 ***
Distance of the focal firm to the closest funding participating venture capital firm (miles)	DistanceClosestVCF	0.0002	0.0001 ***	0.0001 **
Total number of universities located in the focal firm's Metropolitan Statistical Area	UniversitiesInMSA	0.0125	0.0077	0.0079
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the second round of investment	VCFarea_0010_2	0.0013	0.0021	0.0014
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the second round of investment	VCFarea_1020_2	0.0041	0.0026	0.0029
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the second round of investment	PATENTarea_0010_2	0.0003	0.0003	0.0003
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the second round of investment	PATENTarea_1020_2	0.0003	0.0006	0.0006
Age of a biotechnology firm from foundation to the second round of investment (years)	AGE2	0.0020	0.0212	0.0164
Interaction term: patents granted between rounds * universities in the MSA	INTERACTION_2	-0.0011	0.0076	0.0086
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2011	YearDummy_2011	-0.1177	0.3414	0.2756
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2010	YearDummy_2010	0.1723	0.2696	0.3026
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2009	YearDummy_2009	0.0558	0.2445	0.2882
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2008	YearDummy_2008	-0.4224	0.2547	0.3143
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2006	YearDummy_2006	-0.0641	0.2452	0.2577
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2005	YearDummy_2005	-0.1034	0.2394	0.2673
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2004	YearDummy_2004	0.0163	0.2441	0.2262
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2003	YearDummy_2003	0.3635	0.2617	0.2746
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2002	YearDummy_2002	0.1925	0.2535	0.2279
Dummy variable that takes the value of 1 if the round of investment takes place in the year 2001	YearDummy_2001	0.0355	0.5085	0.7200
	R^2	0.4378		
	Adjusted R^2	0.4013		
	F-test for overall model significance		11.26 ***	341.4 ***
	Multicollinearity Condition Number	13.40		
	X^2 for Breusch-Pagan test for heteroskedasticity	9.53 ***		
	Join test of significance PatentApp_2 & PATENTGrant_2	0.36		
	Number of observations	494		

The ommitted year is 2007

Table 4_1

Table 4. Model 1. Estimated coefficients from the Heckman Selection Model of the first round of financing. The Dependent Variable is the natural log of the amount of venture capital funds invested by a biotechnology firm for the first round of financing.

Variable Description	Variable code	Coefficient	Standard Errors
	Intercept	12.28935	0.2292 ***
Number of patent applications filed by a biotechnology firm from foundation to the first round of investment	PATENTApp_1	0.0880	0.0444 **
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment	PATENTGrant_1	-0.0672	0.0466
Average number of forward patent citations per year of patents granted between firm foundation and the first round of investment	PATENTCiteYear_1	-0.0620	0.1327
Variable that assumes increasing values for first round investments directed towards later stages of firm growth	GrowthStage_1	0.4441	0.1396 ***
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment	VCFReputation_1	0.0003	0.0001
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms	FounderSignal	0.3861	0.0329 ***
Number of venture capital firms participating in the first round of investment	SyndicateInvestors_1	0.2291	0.1408 ***
Average sum the funding venture capital firms had invested prior to investing in the focal firm for the first round of investment ($1,000,000)	SyndicateSize_1	0.0004	0.0001 ***
Distance of the focal firm to the closest funding participating venture capital firm (miles)	DistanceClosestVCF	0.0010	0.0081 ***
Total number of universities located in the focal firm's Metropolitan Statistical Area	UniversitiesInMSA	0.0082	0.0024
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the first round of investment	VCFarea_0010_1	0.0026	0.0030 ***
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the first round of investment	VCFarea_1020_1	0.0008	0.0004
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the first round of investment	PATENTarea_0010_1	-0.0002	0.0007 **
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the first round of investment	PATENTarea_1020_1	0.0822	0.0206
Age of a biotechnology firm from foundation to the first round of investment (years)	AGE1	0.3745	0.0834 ***
Interaction term: patents granted before investment round 1 * universities in the MSA	INTERACTION_1	-0.0029	0.0116
Year Dummy Variables Included			YES
	HECKMAN SELECTION STAGE		
	Intercept	-125.9853	99.4313
Dummy variable which takes the value of 1 if a biotechnology firm received SBIR funds	SBIR	-7.1722	96.0078
Dummy variable which takes the value of 1 if a biotechnology firm is located in either MA or CA.	STATE	-0.1698	0.1350
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms.	FounderSignal	0.3076	0.1516 **
Number of patents granted to a firm up to 2006 for SBIR firms or up to the first round of investment for VC-backed firms.	PATENTGrants	0.0017	0.0023
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the first round of investment (or after foundation for firms that did not receive venture capital funds)	VCFarea_0010_1	0.0102	0.0028 ***
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the first round of investment (or after foundation for firms that did not receive venture capital funds)	VCFarea_1020_1	0.0110	0.0029 ***
The year of foundation of the focal firm.	Founded	0.0659	0.0130 ***
	Inverse Mills Ratio	-0.1673	0.0952
	Number of Obs	1,680	
	Censored Obs	1,094	
	Uncensored Obs	586	
	Multicollinearity Condition Number, Stage 2	27.27	
	Multicollinearity Condition Number, Stage 1	4.21	
	Wald Chi^2 (25)	417	

Table 4_2

Table 4 continued. Model 2. Estimated coefficients from the Heckman Selection Model of the second round of financing. The Dependent Variable is the natural log of the amount of venture capital funds invested by a biotechnology firm for the first round of financing.

Variable Description	Variable code	Coefficient	Standard Errors
	Intercept	13.6456	0.5493 ***
Number of patent applications filed by a biotechnology firm from foundation to the first round of investment	PATENTApp_1	0.0315	0.0486
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment	PATENTGrant_1	0.0513	0.1053
Number of patent applications filed by a biotechnology firm from the first round of investment to the second round of investment	PATENTApp_2	-0.0012	0.0403
Number of patents granted to a biotechnology firm from the first round of investment to the second round of investment	PATENTGrant_2	0.0154	0.1023
Average number of forward patent citations per year of patents granted between firm foundation and the first round of investment	PATENTCiteYear_1	-0.1105	0.1425
Average number of forward patent citations per year of patents granted between the first round of investment and the second round of investment	PATENTCiteYear_2	0.0730	0.1024
Total amount of venture capital funded to a biotechnology firm for the first round of investment ($1,000,000)	VCF_Investment_1	0.0269	0.0052 ***
Variable that assumes increasing values for second round investments directed towards later stages of firm growth	GrowthStage_2	0.0578	0.0725
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment	VCFReputation_1	-0.1286	0.2191
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms	FounderSignal	0.0409	0.2376
Number of venture capital firms participating in the second round of investment	SyndicateInvestors_2	0.3290	0.0273 ***
Average sum the funding venture capital firms had invested prior to investing in the focal firm for the second round of investment ($1,000,000)	SyndicateSize_2	0.0006	0.0001 ***
Distance of the focal firm to the closest funding participating venture capital firm (miles)	DistanceClosestVCF	0.0002	0.0001 ***
Total number of universities located in the focal firm's Metropolitan Statistical Area	UniversitiesInMSA	0.0133	0.0080
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the second round of investment	VCFarea_0010_2	0.0004	0.0024
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the second round of investment	VCFarea_1020_2	0.0037	0.0030
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the second round of investment	PATENTarea_0010_2	0.0001	0.0004
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the second round of investment	PATENTarea_1020_2	0.0002	0.0007
Age of a biotechnology firm from foundation to the second round of investment (years)	AGE2	0.0063	0.0204
Interaction term: patents granted before investment round 1 * universities in the MSA	INTERACTION_2	-0.0031	0.0101
Year Dummy Variables Included			YES
	HECKMAN SELECTION STAGE		
	Intercept	0.1277	0.1095
Dummy variable which takes the value of 1 if a biotechnology firm is located in either MA or CA.	STATE	0.2978	0.0899 ***
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment	PATENTGrant_1	-0.0583	0.0327
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms.	FounderSignal	0.4220	0.1421 ***
Variable that assumes increasing values for investments directed towards later stages of firm growth	GrowthStage_2	-0.2435	0.0546 ***
An index that is increasing with the average reputation score of the participating venture capital firms in the previous investment round	VCFreputation_1	0.5146	0.1099 ***
Total amount of venture capital funded to a biotechnology firm for the first round of investment ($1,000,000)	USD_Independent_1	0.0014	0.0024
	Inverse Mills Ratio	-0.4524	0.5755
	Number of Obs	783	
	Censored Obs	289	
	Uncensored Obs	494	
	Multicollinearity Condition Number, Stage 2	13.40	
	Multicollinearity Condition Number, Stage 1	6.75	
	Wald Chi2 (25)	320	***

Table 4_3

Table 4 continued. Model 3. Estimated coefficients for the model of the first round of financing from 1974 to 2011 without patent applications. The Dependent Variable is the natural log of the amount of venture capital funds invested by a biotechnology firm for the first round of financing.

Variable Description	Variable code	Coefficient	Heteroskedasticity robust standard errors	Standard errors clustered at the state level
	Intercept	11.8688	0.1562 ***	0.2305 ***
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment	PATENTGrant_1	-0.0505	0.0520	0.0528
Average number of forward patent citations per year of patents granted between firm foundation and the first round of investment	PATENTCiteYear_1	0.0661	0.0810	0.0563
Variable that assumes increasing values for first round investments directed towards later stages of firm growth	GrowthStage_1	0.3599	0.0716 ***	0.0668 ***
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment	VCFReputation_1	0.1455	0.0976	0.1303
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms	FounderSignal	0.5348	0.1062 ***	0.0940 ***
Number of venture capital firms participating in the first round of investment	SyndicateInvestors_1	0.3599	0.0274 ***	0.0322 ***
Average sum the funding venture capital firms had invested prior to investing in the focal firm for the first round of investment ($1,000,000)	SyndicateSize_1	0.0004	0.0001 ***	0.0002 ***
Variable that assumes increasing values for second round investments directed towards later stages of firm growth	DistanceClosestVCF	0.0003	0.0001 ***	0.0001 ***
An index that is increasing with the average reputation score of the participating venture capital firms in the previous investment round	UniversitiesInMSA	-0.0002	0.0057	0.0058
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the first round of investment	VCFarea_0010_1	0.0088	0.0019 ***	0.0016 ***
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the first round of investment	VCFarea_1020_1	0.0025	0.0022	0.0027
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the first round of investment	PATENTarea_0010_1	0.0007	0.0003 **	0.0003 **
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the first round of investment	PATENTarea_1020_1	0.0000	0.0005	0.0005
Age of a biotechnology firm from foundation to the first round of investment (years)	AGE1	0.0379	0.0125 ***	0.0129 ***
Interaction term: patents granted before investment round 1 * universities in the MSA	INTERACTION_1	0.0032	0.0024	0.0024
Year Dummy Variables Included			YES	
	R^2	0.3924		
	Adjusted R^2	0.3708		
	F-test for overall model significance		16.97 ***	398 ***
	Multicollinearity Condition Number	12.65		
	X^2 for Breusch-Pagan test for heteroskedasticitv	11.78 ***		
	Observations	1,051		

Table 4_4

Table 4 continued. Model 4. Estimated coefficients for the model of the second round of financing from 1974 to 2011 without patent applications. The Dependent Variable is the natural log of the amount of venture capital funds invested by a biotechnology firm for the second round of financing.

Variable Description	Variable code	Coefficient	Heteroskedasticity robust standard errors	Standard errors clustered at the state level
	Intercept	12.9011	0.1589 ***	0.1784 ***
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment	PATENTGrant_1	0.0403	0.0423	0.0395
Number of patents granted to a biotechnology firm from the first round of investment to the second round of investment	PATENTGrant_2	0.0237	0.0359	0.0388
Average number of forward patent citations per year of patents granted between firm foundation and the first round of investment	PATENTCiteYear_1	-0.0149	0.0779	0.0280
Average number of forward patent citations per year of patents granted between the first round of investment and the second round of investment	PATENTCiteYear_2	-0.0006	0.0266	0.0694
Total amount of venture capital funded to a biotechnology firm for the first round of investment ($1,000,000)	VCF_Investment_1	0.0294	0.0058 ***	0.0052 ***
Variable that assumes increasing values for investments directed towards later stages of firm growth	GrowthStage_2	0.0162	0.0490	0.0309
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment	VCFReputation_1	-0.0584	0.0971	0.1051
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms	FounderSignal	0.4793	0.1103 ***	0.1274 ***
Number of venture capital firms participating in the second round of investment	SyndicateInvestors_2	0.2440	0.0170 ***	0.0185 ***
Average sum the funding venture capital firms had invested prior to investing in the focal firm for the second round of investment ($1,000,000)	SyndicateSize_2	0.0007	0.0001 ***	0.0001 ***
Distance of the focal firm to the closest funding participating venture capital firm (miles)	DistanceClosestVCF	0.0002	0.0001 ***	0.0001 ***
Total number of universities located in the focal firm's Metropolitan Statistical Area	UniversitiesInMSA	0.0095	0.0050	0.0041 **
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the second round of investment	VCFarea_0010_2	0.0036	0.0018 **	0.0009 ***
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the second round of investment	VCFarea_1020_2	0.0044	0.0021 **	0.0029
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the second round of investment	PATENTarea_0010_2	0.0002	0.0003	0.0002
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the second round of investment	PATENTarea_1020_2	0.0005	0.0005	0.0006
Age of a biotechnology firm from foundation to the second round of investment (years)	AGE2	0.0231	0.0117 **	0.0054
Interaction term: patents granted between rounds * universities in the MSA	INTERACTION_2	-0.0004	0.0009	0.0010
Year Dummy Variables Included			YES	
	R^2	0.4198		
	Adjusted R^2	0.3933		
	F-test for overall model significance		15.55 ***	412 ***
	Multicollinearity Condition Number	11.615		
	X^2 for Breusch-Pagan test for heteroskedasticity	27.36 ***		
	Observations	918		

Table 4_5

Table 4 continued. Model 5. Estimated coefficients for the model of the first round of financing without outliers on patent applications. The Dependent Variable is the natural log of the amount of venture capital funds invested by a biotechnology firm for the first round of financing.

Variable Description	Variable code	Coefficient	Heteroskedasticity robust standard errors	Standard errors clustered at the state level
	Intercept	12.3063	0.2617 ***	0.4150 ***
Number of patent applications filed by a biotechnology firm from foundation to the first round of investment	PATENTApp_1	0.1515	0.0669 **	0.0428 ***
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment	PATENTGrant_1	-0.0710	0.0517	0.0490
Average number of forward patent citations per year of patents granted between firm foundation and the first round of investment	PATENTCiteYear_1	-0.0869	0.0793	0.0866
Variable that assumes increasing values for first round investments directed towards later stages of firm growth	GrowthStage_1	0.3608	0.0971 ***	0.0766 ***
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment	VCFReputation_1	0.2313	0.1287	0.1670
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms	FounderSignal	0.4621	0.1375 ***	0.1133 ***
Number of venture capital firms participating in the first round of investment	SyndicateInvestors_1	0.3863	0.0371 ***	0.0555 ***
Variable that assumes increasing values for second round investments directed towards later stages of firm growth	SyndicateSize_1	0.0003	0.0001 ***	0.0002
An index that is increasing with the average reputation score of the participating venture capital firms in the previous investment round	DistanceClosestVCF	0.0003	0.0001 ***	0.0001 ***
Total number of universities located in the focal firm's Metropolitan Statistical Area	UniversitiesInMSA	0.0015	0.0080	0.0101
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the first round of investment	VCFarea_0010_1	0.0086	0.0023 ***	0.0029 ***
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the first round of investment	VCFarea_1020_1	0.0031	0.0029	0.0032
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the first round of investment	PATENTarea_0010_1	0.0008	0.0004 **	0.0004
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the first round of investment	PATENTarea_1020_1	-0.0002	0.0007	0.0007
Age of a biotechnology firm from foundation to the first round of investment (years)	AGE1	0.0725	0.0231 ***	0.0225 ***
Interaction term: patents granted before investment round 1 * universities in the MSA	INTERACTION_1	-0.0055	0.0120	0.0072
Year Dummy Variables Included			YES	
	R^2	0.4144		
	Adjusted R^2	0.3842		
	F-test for overall model significance		15.09 ***	114.78 ***
	Multicollinearity Condition Number	13.35		
	X^2 for Breusch-Pagan test for heteroskedasticity	13.99 ***		
	Join test of significance PATENTApp_1 & PATENTGrant_1	3.68 ***		
	Observations	582		

Table 4_6

Table 4 continued. Model 6. Estimated coefficients for the model of the second round of financing without outliers on patent applications from the first and second round of financing. The Dependent Variable is the natural log of the amount of venture capital funds invested by a biotechnology firm for the second round of financing.

Variable Description	Variable code	Coefficient	Heteroskedasticity robust standard errors	Standard errors clustered at the state level
	Intercept	13.1415	0.2599	0.2922
Number of patent applications filed by a biotechnology firm from foundation to the first round of investment	PATENTApp_1	0.0640	0.0885	0.0571
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment	PATENTGrant_1	0.0724	0.1133	0.1303
Number of patent applications filed by a biotechnology firm from the first round of investment to the second round of investment	PATENTApp_2	0.0348	0.0703	0.0614
Number of patents granted to a biotechnology firm from the first round of investment to the second round of investment	PATENTGrant_2	-0.0122	0.1116	0.1214
Average number of forward patent citations per year of patents granted between firm foundation and the first round of investment	PATENTCiteYear_1	-0.1296	0.0709	0.0718
Average number of forward patent citations per year of patents granted between the first round of investment and the second round of investment	PATENTCiteYear_2	0.0678	0.0517	0.0616
Total amount of venture capital funded to a biotechnology firm for the first round of investment ($1,000,000)	VCF_Investment_1	0.0313	0.0068 ***	0.0067 ***
Variable that assumes increasing values for investments directed towards later stages of firm growth	GrowthStage_2	0.0274	0.0706	0.0554
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment	VCFReputation_1	0.0176	0.1369	0.1368
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms	FounderSignal	0.2235	0.1483	0.1830
Number of venture capital firms participating in the second round of investment	SyndicateInvestors_2	0.3286	0.0292 ***	0.0409 ***
Average sum the funding venture capital firms had invested prior to investing in the focal firm for the second round of investment ($1,000,000)	SyndicateSize_2	0.0006	0.0001 ***	0.0001 ***
Distance of the focal firm to the closest funding participating venture capital firm (miles)	DistanceClosestVCF	0.0002	0.0001 ***	0.0001
Total number of universities located in the focal firm's Metropolitan Statistical Area	UniversitiesInMSA	0.0103	0.0079	0.0075
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the second round of investment	VCFarea_0010_2	0.0019	0.0021	0.0014
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the second round of investment	VCFarea_1020_2	0.0042	0.0026	0.0030
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the second round of investment	PATENTarea_0010_2	0.0002	0.0003	0.0003
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the second round of investment	PATENTarea_1020_2	0.0002	0.0006	0.0006
Age of a biotechnology firm from foundation to the second round of investment (years)	AGE2	-0.0010	0.0213	0.0161
Interaction term: patents granted between rounds * universities in the MSA	INTERACTION_2	-0.0032	0.0091	0.0098
Year Dummy Variables Included			YES	
	R^2	0.4291		
	Adjusted R^2	0.3915		
	F-test for overall model significance		11.12 ***	308 ***
	Multicollinearity Condition Number	13.33		
	X^2 for Breusch-Pagan test for heteroskedasticity	9.5 ***		
	Join test of significance PATENTApp_2 & PATENTGrant_2	0.35		
	Observations	485		

Table 4_7

Table 4 continued. Model 7. Estimated coefficients for Pooled Regression. The Dependent Variable is the natural log of the amount of venture capital funds invested by a biotechnology firm in the first or second round of financing.

Variable Description	Variable code	Coefficient	Standard Errors
	Intercept	13.5865	0.9747 ***
Dummy variable that takes the value of 1 for investments of the first round, 0 othetrwise	R1_Dummy	-0.2388	0.0718 ***
Interaction between the round 1 dummy and number of patent applications filed by a biotechnology firm between firm foundation and the first round of investment or between the first and second round of investment	R1_PatentApp	0.0896	0.0329 **
Number of patent applications filed by a biotechnology firm between firm foundation and the first round of investment or between the first and second round of investment	PATENTApp	-0.0459	0.0187 **
Interaction between the the round 1 dummy and number of patents granted to a biotechnology firm between firm foundation and the first round of investment or between the first and second round of investment	R1_PatentGrant	-0.0285	0.0316
Number of patents granted to a biotechnology firm between firm foundation and the first round of investment or between the first and second round of investment	PATENTGrant	-0.0053	0.1143
Average number of forward patent citations per year of patents granted between firm foundation and the first round of investment or between the first and second round of investment	PATENTCiteYear	0.0073	0.0657
Variable that assumes increasing values for investments directed towards later stages of firm growth	GrowthStage	0.0749	0.0760
Variable that assumes increasing values for second round investments directed towards later stages of firm growth	SyndicateInvestors	0.3286	0.0265 ***
An index that is increasing with the average reputation score of the participating venture capital firms in the previous investment round	SyndicateSize	0.0004	0.0000 ***
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the focal round of investment	VCFarea_0010	0.0503	0.0217 **
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the focal round of investment	VCFarea_1020	0.0180	0.0494
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the focal round of investment	PATENTarea_0010	-0.0072	0.0016 ***
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the focal round of investment	PATENTarea_1020	-0.0022	0.0011 ***
Age of a biotechnology firm from foundation to the focal round of investment (years)	AGE	-0.0123	0.0043 **
Interaction term: patents granted before investment round 1 * universities in the MSA	INTERACTION	-0.0013	0.0043
Year Dummy Variables Included		YES	
	R^2 Within	0.2979	
	R^2 Between	0.0988	
	R^2 Overall	0.1047	
	F-test for overall model significance	551.98	***
	Rho	0.80	
	Multicollinearity Condition Number	42.23	
	Number of Observations	988	

Table 4_8

Table 4 continued. Model 8. Estimated coefficients for the model of the second round of financing without patent activity measures of financing round one. The Dependent Variable is the natural log of the amount of venture capital funds invested by a biotechnology firm for the second round of financing.

Variable Description	Variable code	Coefficient	Heteroskedasticity robust standard errors	Standard errors clustered at the state level
	Intercept	13.1200	0.2576 ***	0.2839 ***
Number of patent applications filed by a biotechnology firm from foundation to the first round of investment	PATENTApp_1	-	-	-
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment	PATENTGrant_1	-	-	-
Number of patent applications filed by a biotechnology firm from the first round of investment to the second round of investment	PATENTApp_2	0.0045	0.0348	0.0278
Number of patents granted to a biotechnology firm from the first round of investment to the second round of investment	PATENTGrant_2	0.0459	0.0332	0.0260
Average number of forward patent citations per year of patents granted between firm foundation and the first round of investment	PATENTCiteYear_1	-	-	-
Average number of forward patent citations per year of patents granted between the first round of investment and the second round of investment	PATENTCiteYear_2	0.0526	0.0557	0.0278
Total amount of venture capital funded to a biotechnology firm for the first round of investment ($1,000,000)	VCF_Investment_1	0.0265	0.0066 ***	0.0260 ***
Variable that assumes increasing values for second round investments directed towards later stages of firm growth	GrowthStage_2	0.0283	0.0705	0.0586
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment	VCFReputation_1	0.0530	0.1366	0.1268
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms	FounderSignal	0.2376	0.1453	0.1714
Number of venture capital firms participating in the second round of investment	SyndicateInvestors_2	0.3332	0.0284 ***	0.0384 ***
Average sum the funding venture capital firms had invested prior to investing in the focal firm for the second round of investment ($1,000,000)	SyndicateSize_2	0.0006	0.0001 ***	0.0001 ***
Distance of the focal firm to the closest funding participating venture capital firm (miles)	DistanceClosestVCF	0.0002	0.0001 ***	0.0001 **
Total number of universities located in the focal firm's Metropolitan Statistical Area	UniversitiesInMSA	0.0137	0.0075	0.0080
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the second round of investment	VCFarea_0010_2	0.0009	0.0021	0.0014
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the second round of investment	VCFarea_1020_2	0.0041	0.0026	0.0029
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the second round of investment	PATENTarea_0010_2	0.0003	0.0003	0.0003
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the second round of investment	PATENTarea_1020_2	0.0003	0.0006	0.0006
Age of a biotechnology firm from foundation to the second round of investment (years)	AGE2	0.0006	0.0211	0.0165
Interaction term: patents granted between investment rounds 1 and 2 * universities in the MSA	INTERACTION_2	-0.0027	0.0044	0.0040
Year Dummy Variables Included			YES	
	R^2	0.4340		
	Adjusted R^2	0.4013		
	F-test for overall model significance		11.74 ***	91.47 ***
	Multicollinearity Condition Number	13.34		
	X^2 for Breusch-Pagan test for heteroskedasticity	9.41 ***		
	Join test of significance PATENTApp_2 & PATENTGrant_2	1.08		
	Observations	496		

Table 4_9

Table 4 continued. Model 9. Estimated coefficients for the model of the second round of financing including only the variables that measure granted patents for the first and second round of investment. The Dependent Variable is the natural log of the amount of venture capital funds invested by a biotechnology firm for the second round of financing.

Variable Description	Variable code	Coefficient	Heteroskedasticity robust standard errors	Standard errors clustered at the state level
	Intercept	13.1035	0.2579 ***	0.2814 ***
Number of patent applications filed by a biotechnology firm from foundation to the first round of investment	PATENTApp_1	-	-	-
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment	PATENTGrant_1	0.0568	0.0926	0.1097
Number of patent applications filed by a biotechnology firm from the first round of investment to the second round of investment	PATENTApp_2	-	-	-
Number of patents granted to a biotechnology firm from the first round of investment to the second round of investment	PATENTGrant_2	0.0045	0.0924	0.1042
Average number of forward patent citations per year of patents granted between firm foundation and the first round of investment	PATENTCiteYear_1	-0.1060	0.0899	0.0873
Average number of forward patent citations per year of patents granted between the first round of investment and the second round of investment	PATENTCiteYear_2	0.0696	0.0506	0.0642
Total amount of venture capital funded to a biotechnology firm for the first round of investment ($1,000,000)	VCF_Investment_1	0.0268	0.0068 ***	0.0068 ***
Variable that assumes increasing values for second round investments directed towards later stages of firm growth	GrowthStage_2	0.0344	0.0707	0.0594
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment	VCFReputation_1	0.0534	0.1376	0.1298
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms	FounderSignal	0.2372	0.1459	0.1784
Number of venture capital firms participating in the second round of investment	SyndicateInvestors_2	0.3318	0.0275 ***	0.0355 ***
Average sum the funding venture capital firms had invested prior to investing in the focal firm for the second round of investment ($1,000,000)	SyndicateSize_2	0.0006	0.0001 ***	0.0001 ***
Distance of the focal firm to the closest funding participating venture capital firm (miles)	DistanceClosestVCF	0.0002	0.0001 ***	0.0001 **
Total number of universities located in the focal firm's Metropolitan Statistical Area	UniversitiesInMSA	0.0122	0.0077	0.0078
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the second round of investment	VCFarea_0010_2	0.0012	0.0021	0.0014
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the second round of investment	VCFarea_1020_2	0.0041	0.0026	0.0029
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the second round of investment	PATENTarea_0010_2	0.0003	0.0003	0.0003
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the second round of investment	PATENTarea_1020_2	0.0003	0.0006	0.0006
Age of a biotechnology firm from foundation to the second round of investment (years)	AGE2	0.0025	0.0210	0.0163
Interaction term: patents granted between investment rounds 1 and 2 * universities in the MSA	INTERACTION_2	-0.0003	0.0070	0.0076
Year Dummy Variables Included			YES	
	R^2	0.4375		
	Adjusted R^2	0.4036		
	F-test for overall model significance		11.88 ***	171.60 ***
	Multicollinearity Condition Number	13.40		
	X^2 for Breusch-Pagan test for heteroskedasticity	9.22 ***		
	Observations	494		

Table 4_10

Table 4 continued. Model 10. Estimated coefficients for the model of the first round of financing without the patent activity and citation measures. The Dependent Variable is the natural log of the amount of venture capital funds invested by a biotechnology firm for the first round of financing.

Variable Description	Variable code	Coefficient	Heteroskedasticity robust standard errors	Standard errors clustered at the state level
	Intercept	12.2724	0.2616 ***	0.4192 ***
Number of patent applications filed by a biotechnology firm from foundation to the first round of investment	PATENTApp_1	-	-	-
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment	PATENTGrant_1	-	-	-
Average number of forward patent citations per year of patents granted between firm foundation and the first round of investment	PATENTCiteYear_1	-	-	-
Variable that assumes increasing values for first round investments directed towards later stages of firm growth	GrowthStage_1	0.3721	0.0972 ***	0.0794 ***
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment	VCFReputation_1	0.2142	0.1299	0.1667
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms	FounderSignal	0.4250	0.1366 ***	0.1152 ***
Number of venture capital firms participating in the first round of investment	SyndicateInvestors_1	0.3940	0.0372 ***	0.0559 ***
Variable that assumes increasing values for second round investments directed towards later stages of firm growth	SyndicateSize_1	0.0003	0.0001 ***	0.0002
An index that is increasing with the average reputation score of the participating venture capital firms in the previous investment round	DistanceClosestVCF	0.0003	0.0001 ***	0.0001 ***
Total number of universities located in the focal firm's Metropolitan Statistical Area	UniversitiesInMSA	0.0028	0.0079	0.0098
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the first round of investment	VCFarea_0010_1	0.0085	0.0023 ***	0.0028 ***
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the first round of investment	VCFarea_1020_1	0.0030	0.0028	0.0031
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the first round of investment	PATENTarea_0010_1	0.0008	0.0004 **	0.0004
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the first round of investment	PATENTarea_1020_1	-0.0002	0.0007	0.0007
Age of a biotechnology firm from foundation to the first round of investment (years)	AGE1	0.0800	0.0228 ***	0.0229 ***
Interaction term: patents granted before investment round 1 * universities in the MSA	INTERACTION_1	-0.0135	0.0119	0.0077
Year Dummy Variables Included			YES	
	R^2	0.4072		
	Adjusted R^2	0.3830		
	F-test for overall model significance		16.82 ***	106.30 ***
	Multicollinearity Condition Number	13.23		
	X^2 for Breusch-Pagan test for heteroskedasticitv	12.37 ***		
	Observations	586		

Table 4_11

Table 4 continued. Model 11. Estimated coefficients for the model of the second round of financing without the patent activity and citation measures. The Dependent Variable is the natural log of the amount of venture capital funds invested by a biotechnology firm for the second round of financing.

Variable Description	Variable code	Coefficient	Heteroskedasticity robust standard errors	Standard errors clustered at the state level
	Intercept	13.1349	0.2552 ***	0.2843 ***
Number of patent applications filed by a biotechnology firm from foundation to the first round of investment	PATENTApp_1	-	-	-
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment	PATENTGrant_1	-	-	-
Number of patent applications filed by a biotechnology firm from the first round of investment to the second round of investment	PATENTApp_2	-	-	-
Number of patents granted to a biotechnology firm from the first round of investment to the second round of investment	PATENTGrant_2	-	-	-
Average number of forward patent citations per year of patents granted between firm foundation and the first round of investment	PATENTCiteYear_1	-	-	-
Average number of forward patent citations per year of patents granted between the first round of investment and the second round of investment	PATENTCiteYear_2	-	-	-
Total amount of venture capital funded to a biotechnology firm for the first round of investment ($1,000,000)	VCF_Investment_1	0.0266	0.0067 ***	0.0067 ***
Variable that assumes increasing values for second round investments directed towards later stages of firm growth	GrowthStage_2	0.0316	0.0702	0.0594
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment	VCFReputation_1	0.0515	0.1363	0.1266
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms	FounderSignal	0.2457	0.1448	0.1713
Number of venture capital firms participating in the second round of investment	SyndicateInvestors_2	0.3324	0.0271 ***	0.0351 ***
Average sum the funding venture capital firms had invested prior to investing in the focal firm for the second round of investment ($1,000,000)	SyndicateSize_2	0.0006	0.0001 ***	0.0001 ***
Distance of the focal firm to the closest funding participating venture capital firm (miles)	DistanceClosestVCF	0.0002	0.0001 ***	0.0001 **
Total number of universities located in the focal firm's Metropolitan Statistical Area	UniversitiesInMSA	0.0123	0.0074	0.0081
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the second round of investment	VCFarea_0010_2	0.0010	0.0021	0.0014
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the second round of investment	VCFarea_1020_2	0.0041	0.0026	0.0029
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the second round of investment	PATENTarea_0010_2	0.0002	0.0003	0.0002
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the second round of investment	PATENTarea_1020_2	0.0003	0.0006	0.0006
Age of a biotechnology firm from foundation to the second round of investment (years)	AGE2	0.0034	0.0206	0.0161
Interaction term: patents granted between investment rounds 1 and 2 * universities in the MSA	INTERACTION_2	0.0014	0.0038	0.0033
Year Dummy Variables Included			YES	
	R^2	0.4325		
	Adjusted R^2	0.4036		
	F-test for overall model significance		13.27 ***	71.68 ***
	Multicollinearity Condition Number	13.14		
	X^2 for Breusch-Pagan test for heteroskedasticitv	9.22 ***		
	Observations	496		

Table 4_12

Table 4 continued. Model 12. Estimated coefficients for the model of the first round of financing. The number of forward citations is replaced by the patent family. The Dependent Variable is the natural log of the amount of venture capital funds invested by a biotechnology firm for the first round of financing.

Variable Description	Variable code	Coefficient	Heteroskedasticity robust standard errors	Standard errors clustered at the state level
	Intercept	12.2782	0.2613 ***	0.4182 ***
Number of patent applications filed by a biotechnology firm from foundation to the first round of investment	PATENTApp_1	0.0753	0.0305 **	0.0289 **
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment	PATENTGrant_1	-0.0717	0.0510	0.0480
Average family size of patents granted from firm foundation and the first round of investment	PATENTFamilySize_1	-0.0009	0.0030	0.0030
Variable that assumes increasing values for investments directed towards later stages of firm growth	GrowthStage_1	0.3610	0.0978 ***	0.0759 ***
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment	VCFReputation_1	0.2329	0.1280	0.1657
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms	FounderSignal	0.4552	0.1378 ***	0.1206 ***
Number of venture capital firms participating in the first round of investment	SyndicateInvestors_1	0.3885	0.0371 ***	0.0547 ***
Variable that assumes increasing values for second round investments directed towards later stages of firm growth	SyndicateSize_1	0.0003	0.0001 ***	0.0002
An index that is increasing with the average reputation score of the participating venture capital firms in the previous investment round	DistanceClosestVCF	0.0004	0.0001 ***	0.0001 ***
Total number of universities located in the focal firm's Metropolitan Statistical Area	UniversitiesInMSA	0.0019	0.0080	0.0101
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the first round of investment	VCFarea_0010_1	0.0084	0.0023 ***	0.0028 ***
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the first round of investment	VCFarea_1020_1	0.0028	0.0028	0.0032
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the first round of investment	PATENTarea_0010_1	0.0008	0.0004 **	0.0004
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the first round of investment	PATENTarea_1020_1	-0.0002	0.0007	0.0007
Age of a biotechnology firm from foundation to the first round of investment (years)	AGE1	0.0772	0.0226 ***	0.0227 ***
Interaction term: patents granted between investment rounds 1 and 2 * universities in the MSA	INTERACTION_1	-0.0048	0.0121	0.0076
Year Dummy Variables Included		YES		
	R^2	0.4124		
	Adjusted R^2	0.3851		
	F-test for overall model significance		15.18 ***	118.88 ***
	Multicollinearity Condition Number	13.38		
	X^2 for Breusch-Pagan test for heteroskedasticitv	13.80 ***		
	Join test of significance PatentApp 1 & PATENTGrant 1	3.68 **		
	Number of observations	586		

The ommitted year is 2007

Table 4_13

Table 4 continued. Model 13. Estimated coefficients for the model of the second round of financing. The number of forward citations is replaced by the patent family. The Dependent Variable is the natural log of the amount of venture capital funds invested by a biotechnology firm for the second round of financing.

Variable Description	Variable code	Coefficient	Heteroskedasticity robust standard errors	Standard errors clustered at the state level
	Intercept	13.0800	0.2749 ***	0.3049 ***
Number of patent applications filed by a biotechnology firm from foundation to the first round of investment	PATENTApp_1	0.0130	0.0571	0.0557
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment	PATENTGrant_1	0.0083	0.1033	0.1194
Number of patent applications filed by a biotechnology firm from the first round of investment to the second round of investment	PATENTApp_2	0.0086	0.0360	0.0273
Number of patents granted to a biotechnology firm from the first round of investment to the second round of investment	PATENTGrant_2	0.0443	0.1038	0.1101
Average patent family size of patents granted from firm foundation to the first round of investment	PATENTFamilySize_1	0.0053	0.0062	0.0057
Average patent family size of patents granted from the first round of investment to the second round of investment	PATENTFamilySize_2	-0.0009	0.0034	0.0033
Total amount of venture capital funded to a biotechnology firm for the first round of investment ($1,000,000)	VCF_Investment_1	0.0270	0.0069 ***	0.0080 ***
Variable that assumes increasing values for second round investments directed towards later stages of firm growth	GrowthStage_2	0.0632	0.0768	0.0760
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment	VCFReputation_1	0.0723	0.1388	0.1239
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms	FounderSignal	0.1817	0.1494	0.1774
Number of venture capital firms participating in the second round of investment	SyndicateInvestors_2	0.3147	0.0282 ***	0.0389 ***
Average sum the funding venture capital firms had invested prior to investing in the focal firm for the second round of investment ($1,000,000)	SyndicateSize_2	0.0006	0.0001 ***	0.0001 ***
Distance of the focal firm to the closest funding participating venture capital firm (miles)	DistanceClosestVCF	0.0002	0.0001 ***	0.0001 **
Total number of universities located in the focal firm's Metropolitan Statistical Area	UniversitiesInMSA	0.0094	0.0085	0.0115
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the second round of investment	VCFarea_0010_2	0.0013	0.0022	0.0017
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the second round of investment	VCFarea_1020_2	0.0035	0.0027	0.0033
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the second round of investment	PATENTarea_0010_2	0.0002	0.0003	0.0003
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the second round of investment	PATENTarea_1020_2	0.0006	0.0006	0.0006
Age of a biotechnology firm from foundation to the second round of investment (years)	AGE2	-0.0059	0.0224	0.0174
Interaction term: patents granted between investment rounds 1 and 2 * universities in the MSA	INTERACTION_2	-0.0004	0.0078	0.0080
Year Dummy Variables Included		YES		
	R^2	0.4322		
	Adjusted R^2	0.3906		
	F-test for overall model significance		9.37 ***	254 ***
	Multicollinearity Condition Number	13.67		
	X^2 for Breusch-Pagan test for heteroskedasticity	10.19 ***		
	Join test of significance PatentApp 2 & PATENTGrant 2	0.36		
	Number of observations	494		

The ommitted year is 2007

Appendix Table 1

Appendix Table 1. Correlation Coefficients of Variables Used for the First Round of Financing Specification

Variable Description	#	Variable code	ln(USD_R1)	PATENTApp_1	PATENTGrant_1	PATENTCiteYear_1	GrowthStage_1	VCFReputation_1	FounderSignal	SyndicateInvestors_1	SyndicateSize_1	DistanceClosestVCF	UniversitiesInMSA	VCFarea_0010_1	VCFarea_1020_1	PATENTArea_0010_1	PATENTArea_1020_1	AGE__1	INTERACTION_1
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
The natural log of the first round of venture capital funds	1	ln(USD_R1)	1.00																
Number of patent applications filed by a biotechnology firm from foundation to the first round of investment	2	PATENTApp_1	0.10	1.00															
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment	3	PATENTGrant_1	-0.02	0.12	1.00														
Average number of forward patent citations per year of patents granted between firm foundation and the first round of investment	4	PATENTCiteYear_1	-0.01	0.11	0.30	1.00													
Variable that assumes increasing values for investments directed towards later stages of firm growth	5	GrowthStage_1	0.26	0.16	0.12	0.14	1.00												
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment	6	VCFReputation_1	0.27	-0.06	-0.03	-0.03	-0.02	1.00											
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms	7	FounderSignal	0.13	-0.01	0.09	0.01	-0.02	0.17	1.00										
Average sum the funding venture capital firms had invested prior to investing in the focal firm for the first round of investment ($1,000,000)	8	SyndicateInvestors_1	0.49	0.00	-0.04	-0.06	0.13	0.36	0.04	1.00									
Number of venture capital firms participating in the first round of investment	9	SyndicateSize_1	0.18	-0.04	-0.06	-0.07	-0.12	0.28	0.09	0.09	1.00								
Distance of the focal firm to the closest funding participating venture capital firm (miles)	10	DistanceClosestVCF	0.13	0.06	0.07	0.08	0.13	-0.12	-0.09	-0.10	0.07	1.00							
Total number of universities located in the focal firm's Metropolitan Statistical Area	11	UniversitiesInMSA	0.10	-0.04	-0.08	-0.10	0.02	0.06	0.03	0.03	0.06	-0.11	1.00						
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the first round of investment	12	VCFarea_0010_1	0.23	-0.02	-0.07	-0.08	-0.08	0.20	0.11	0.11	0.16	-0.09	0.45	1.00					
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the first round of investment	13	VCFarea_1020_1	0.06	-0.03	-0.04	-0.04	0.02	0.09	-0.04	0.02	0.04	0.01	0.21	0.06	1.00				
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the first round of investment	14	PATENTarea_0010_1	0.16	0.00	-0.07	-0.01	-0.07	0.12	0.01	0.10	0.18	0.07	0.03	0.28	0.13	1.00			
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the first round of investment	15	PATENTarea_1020_1	0.07	-0.03	-0.05	-0.06	-0.03	0.05	-0.03	0.02	0.07	0.03	0.09	0.25	0.64	0.16	1.00		
Age of a biotechnology firm from foundation to the first round of investment (years)	16	AGE1	0.12	0.25	0.25	0.11	0.34	-0.13	-0.02	-0.09	-0.12	0.17	0.00	-0.10	-0.08	-0.16	-0.10	1.00	
Interaction term: patents granted before round 1 * universities in the MSA	17	INTERACTION_1	0.04	0.14	0.51	0.14	0.15	-0.07	-0.01	0.03	-0.07	0.09	0.06	-0.01	0.02	-0.03	-0.01	0.30	1.00

Appendix Table 2

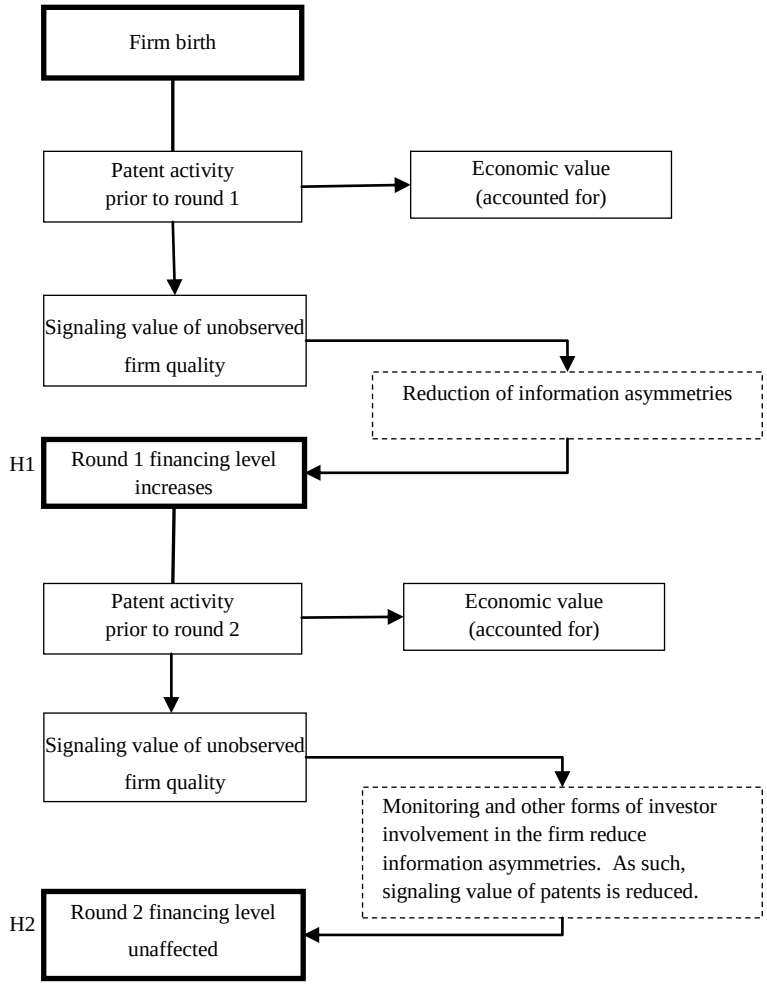
Appendix Table 2. Correlation Coefficients of Variables Used for the Second Round of Financing Specification

Variable Description	#	Variable code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
The natural log of the second round of venture capital funds	1	ln(USD_R2)	1.00																				
Number of patent applications filed by a biotechnology firm from foundation to the first round of investment that did not make it into a granted patent	2	PATENTApp_1	0.03	1.00																			
Number of patent applications filed by a biotechnology firm from the first round of investment to the second round of investment	3	PATENTApp_2	0.16	0.19	1.00																		
Number of patents granted to a biotechnology firm from firm foundation to the first round of investment	4	PATENTGrant_1	0.00	0.07	0.21	1.00																	
Number of patents granted to a biotechnology firm from the first round of investment to the second round of investment	5	PATENTGrant_2	0.04	0.10	0.30	0.78	1.00																
Average number of forward patent citations per year of patents granted between firm foundation and the first round of investment	6	PATENTCiteYear_1	-0.07	0.12	0.07	0.32	0.20	1.00															
Average number of forward patent citations per year of patents granted between the first round of investment and the second round of investment	7	PATENTCiteYear_2	0.00	0.01	0.06	0.16	0.26	0.24	1.00														
Total amount of venture capital funded to a biotechnology firm for the first round of investment ($1,000,000)	8	VCF_Investment_1	0.33	0.03	0.22	-0.02	0.06	-0.04	0.01	1.00													
Variable that assumes increasing values for investments directed towards later stages of firm growth	9	GrowthStage_2	0.18	-0.04	-0.02	-0.07	-0.08	-0.05	-0.01	0.07	1.00												
An index that is increasing with the average reputation score of the participating venture capital firms in the first round of investment	10	VCF_Reputation_1	0.07	0.08	0.15	0.09	0.13	0.09	0.10	0.14	-0.11	1.00											
Dummy variable which takes the value of 1 if a biotechnology firm founder holds a distinguished and/or named professorship and/or is a member of the Academy of Sciences and/or Nobel Prize and/or had previously founded other firms	11	FounderSignal	0.14	-0.03	0.03	0.09	0.12	0.03	0.03	0.11	0.16	0.03	1.00										
Number of venture capital firms participating in the second round of investment	12	SyndicateInvestors_2	0.52	0.04	0.24	-0.04	-0.02	-0.07	-0.04	0.18	0.17	0.10	0.08	1.00									
Average sum the funding venture capital firms had invested prior to investing in the focal firm for the second round of investment ($1,000,000)	13	SyndicateSize_2	0.05	0.04	-0.04	0.05	0.08	0.04	0.03	0.13	-0.13	0.08	-0.08	-0.11	1.00								
Distance of the focal firm to the closest funding participating venture capital firm (miles)	14	DistanceClosestVCF	0.14	-0.06	0.04	-0.08	-0.05	-0.10	-0.07	0.06	0.11	-0.02	0.03	0.05	-0.11	1.00							
Total number of universities located in the focal firm's Metropolitan Statistical Area	15	UniversitiesInMSA	0.21	-0.03	0.07	-0.05	-0.02	-0.07	-0.07	0.12	0.23	-0.08	0.10	0.17	-0.10	0.42	1.00						
Total number of venture capital firms located within 0 to 10 miles from the focal firm founded before the second round of investment	16	VCFarea_0010_2	0.10	0.00	-0.02	-0.03	-0.04	-0.05	-0.02	-0.02	0.12	-0.01	-0.06	-0.01	-0.06	0.23	0.03	1.00					
Total number of venture capital firms located within 10 to 20 miles from the focal firm founded before the second round of investment	17	VCFarea_1020_2	0.16	0.04	-0.03	-0.06	-0.05	-0.08	-0.08	0.03	0.16	-0.11	0.01	0.13	0.03	0.04	0.30	0.12	1.00				
Total number of patents held by biotechnology firms located within 0 to 10 miles from the focal firm before the second round of investment	18	PATENTarea_0010_2	0.12	-0.01	0.02	-0.02	-0.03	-0.05	-0.02	0.03	0.06	-0.02	-0.03	0.01	0.01	0.09	0.23	0.67	0.17	1.00			
Total number of patents held by biotechnology firms located within 10 to 20 miles from the focal firm before the second round of investment	19	PATENTarea_1020_2	0.00	0.03	0.07	0.06	0.09	0.03	0.08	0.04	-0.07	-0.05	0.03	-0.04	0.05	0.07	0.04	0.05	-0.03	0.07	1.00		
Age of a biotechnology firm from foundation to the second round of investment (years)	20	AGE2	-0.06	0.12	0.19	0.16	0.22	0.10	0.06	0.08	0.32	-0.16	0.02	-0.09	-0.18	0.15	0.07	-0.08	-0.08	-0.14	-0.07	1.00	
Interaction term: patent Grants R2 and universties in MSA	21	INTERACTION_2	0.05	0.24	0.20	0.53	0.11	0.17	0.02	-0.07	0.10	0.09	0.12	-0.06	0.02	0.02	0.15	0.05	0.01	-0.01	-0.01	0.19	1.00

Figure 1

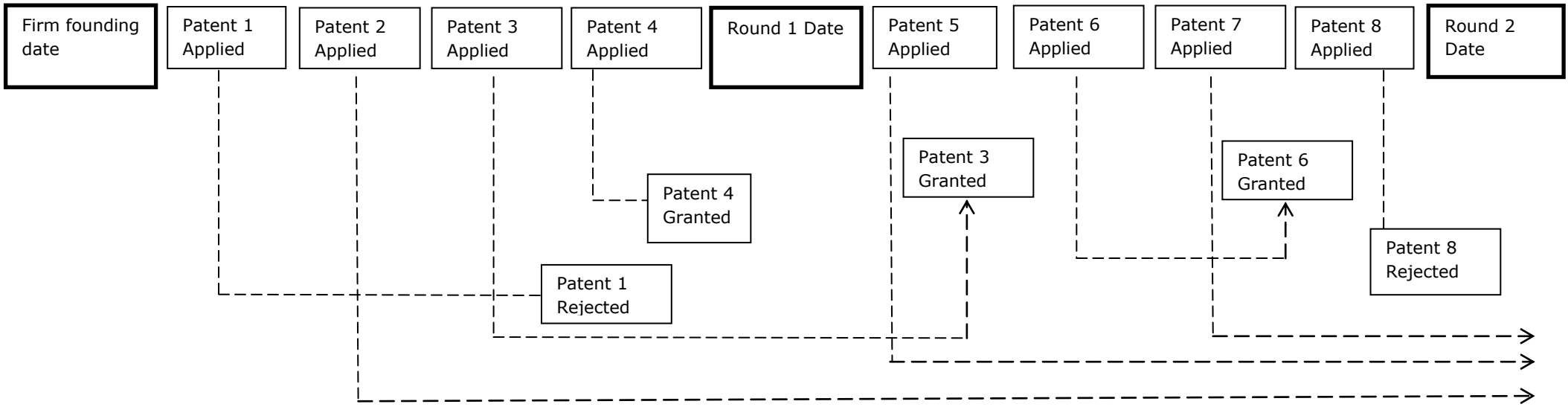
Figure 1. Theoretical Framework

The signaling effect of intellectual property owned by emerging high technology firms on the attraction of external capital



Appendix Figure 1

Appendix Figure 1. Hypothetical scenario illustrating how the patent activity measures are constructed



Values assumed by patent activity measures in the Round 1 regression for the hypothetical scenario	
PatentApp_1	*PatentGrant_1*
3 The application of patent 4 is excluded from the count because patent 4 was granted before the date of round 1 and as such it is included as a grant in the *PatentGrant_1* variable	**1** The grant of patent 4

Values assumed by patent activity measures in the Round 2 regression for the hypothetical scenario			
PatentApp_1	*PatentGrant_1*	*PatentApp_2*	*PatentGrant_2*
2 The application of patent 3 is excluded from the count because patent 3 was granted after round 1 and it is counted in the *PatentGrant_2* variable	**1** The grant of patent 4	**3** The applications of patents 5 ,7 and 8 are included; the application of patent 6 is not included because that application is included as a granted patent in the *PatentGrant_2* variable	**2** The grant of patent 6 and the grant of patent 3